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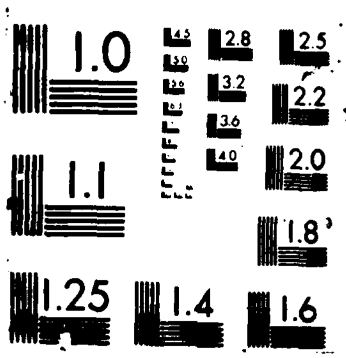
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A PRACTICALITY STUDY OF AIR FORCE
DEPOT MAINTENANCE COST ALLOCATION

THESIS

Bruce M. Kalish, B.S.
Captain, USAF

AFIT/GSM/LSY/87S-12

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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DEPOT MAINTENANCE COST ALLOCATION

THESIS

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Systems Management

Bruce M. Kalish, B.S.

Captain, USAF

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AFIT has made me more aware of the gifts that we individually possess. I will look for these gifts in people. And now, as the author of Hebrews wrote in chapter 12, verse 1, "Let us run with perseverence the race marked out for us."

Bruce Kalish

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Abstract

The purpose of this study was to test the practicality of the present method of allocating depot maintenance costs based on the number of flying hours (FH) and primary authorized aircraft (PAA). The study addressed two basic research questions: (1) Is it reasonable to assume that flying hours and primary authorized aircraft are appropriate variables to use for development of Air Force depot maintenance cost factors? (2) Can percentage allocations presently used for FH and PAA be validated through using a.) regression analysis on fighter and cargo aircraft data, b.) using goal programming as an alternate modeling technique to cross check the regression analysis, and c.) a linear programming formulation as an additional cross check?

The study found that throughout all three statistical approaches, FH is the sole significant variable and PAA is relatively insignificant in explaining cost. Furthermore, results show allocation percentages should be 100% to the variable FH.

Although the use of FH and PAA is "intuitively appealing" and may seem logical FH dominates in all three approaches used in this thesis. Based on this research it appears that it is more appropriate to base depot maintenance cost allocation entirely on the amount of flying

hours. The allocation percentages that are currently used cannot be statistically verified using several programming methods.

Among the recommendations is that more analysis is needed to evaluate other cost drivers that are significant by themselves, when used with FH, or when two or more others are used together. However, the regression models created in this study for fighter and cargo aircraft using FH only are good models. Perhaps consideration should be given to allocating depot maintenance costs entirely to FH.

A PRACTICALITY STUDY OF AIR FORCE DEPOT MAINTENANCE COST ALLOCATION

I. Introduction

General Issue

Air Force Regulation (AFR) 173-13, USAF Cost and Planning Factors, provides standard or expected cost factors for all Air Force aircraft in the active inventory. The purpose of these factors is to provide "timely, accurate, and commonly used factors for decision making processes" (11:1). Two prominent areas where these factors are used is in the budget development cycle and preparing life cycle cost estimates. The factors are updated at least annually. Periodic updates are also issued to reflect the latest factors based on inflation, changing priorities, and increased data availability.

Aircraft depot maintenance cost factors are one type of factor included in AFR 173-13 and contain all "elements of expenditures incurred by the Depot Maintenance Service, Air Force Industrial Fund to inspect, repair, overhaul, or perform other aircraft maintenance not performed at base level" (11:3). Aircraft depot maintenance is a significant element within the operating and support (O&S) phase of the weapon system life cycle. In FY86, total depot maintenance

costs accounted for 53.5% of Air Force Logistics Command's (AFLC) total maintenance costs (source:AFLC/ACB).

Requirements for Cost Factors. Requirements for operating and support (O&S) cost factors stem from overall guidance by the Office of the Secretary of Defense (OSD). General Air Force depot maintenance cost factor requirements are found in AFR 173-4, Aircraft and Missile Depot Maintenance Cost Factors, and working level instructions are detailed in AFR 173-13, USAF Cost and Planning Factors.

OSD Guidance. Presently, direction from the OSD Cost Analysis Improvement Group (CAIG) requires that cost estimates be compatible with the Planning, Programming, and Budgeting System (PPBS). The CAIG, in the Aircraft Operating and Support Cost Development Guide states that

> ... many of the cost elements from those O&S cost analyses should be compatible with approved Program, Planning and Budgeting System (PPBS) costs, and can be used to derive the impact of alternative aircraft choices on programs and budgets. (25:2-3)

General Air Force Guidance. AFR 173-4, Aircraft and Missile Depot Maintenance Cost Factors, provides more specific guidance to be used to develop, report, and publish depot maintenance cost factors for Air Force aircraft. This regulation states that these factors consist of

(1) A variable cost that varies directly and linearly with changes in the operating aircraft inventory.

(2) A variable cost that varies directly and linearly with changes in the flying hour program. (10:1)

Specific Air Force Guidance. Ultimately, HQ USAF/ACC is responsible for developing and providing all USAF cost factors used to estimate operating and support costs or resource requirements (10:1) and is the office of primary responsibility for AFR 173-13. AFR 173-13 specifies that

> [flying hour] FH factors are the variable costs per aircraft associated with each category of semivariable costs .... [primary authorized aircraft] PAA factors are the fixed cost per aircraft associated with each category of semivariable costs. (11:3)

HQ USAF/ACC has directed that data from the Weapon System Cost Retrieval System (WSCRS), which is discussed later in this chapter, be used as the source for developing the depot maintenance cost factors published in AFR 173-13 (12:4).

Current Factor Development Procedure. To comply with OSD and Air Force guidance, depot maintenance costs are assumed to be either inventory (i.e. primary authorized aircraft (PAA)) or usage (i.e. flying hour (FH)) driven (12:78). Following this guidance, depot maintenance cost factors are currently developed by first classifying costs into eight categories called work breakdown structures (WBS). Then, the WBS depot maintenance costs are identified as either being primary authorized aircraft or flying hours dependent by applying the percentages listed in Table 1. The same percentage is applied to the WBS category regardless of the aircraft or Mission, Design, Series (MDS).

Finally, depot maintenance cost per PAA and depot maintenance cost per flying hour factors are computed.

TABLE 1

AIRCRAFT DEPOT MAINTENANCE COST ALLOCATIONS BY WORK BREAKDOWN STRUCTURE (WBS)

WBS CATEGORY	Percent Cost Inventory (PAA) Related	Percent Cost Flying Hour (FH) Related
Aircraft Overhaul	100	0
Engine Overhaul	0	100
Engine Accessories	0	100
Aircraft Accessories	35	65
Avionics Instrumentation	35	65
Avionics Communication	35	65
Avionics Navigation	35	65
Armament	35	65

(12:78)

These cost factors for each WBS within a Mission Design Series (MDS) (e.g. F-16A, C-130H, B-52G) are currently calculated as follows (12:78):

WBS Depot Maintenance Cost per Aircraft =

$$\frac{(\text{WBS Variable Cost}) * (\%)}{\text{PAA}} \qquad [1]$$

WBS Depot Maintenance Cost per Flying Hour =

$$\frac{(\text{WBS Variable Cost}) * (\%)}{\text{FH}} \qquad [2]$$

where: % = the percent application found in Table 1
PAA = Primary Authorized Aircraft Inventory
FH = Flying Hours

However, the allocation percentages in Table 1 are unverified. These allocations come from an undated and

unsigned paper (approximately 1974) found at Headquarters Air Force, Directorate of Cost (USAF/ACC). Therefore, in 1985 USAF/ACC requested a study to determine an appropriate and scientifically verifiable allocation of depot maintenance costs to primary authorized aircraft and flying hours by each aircraft WBS.

Prior to this USAF/ACC request, First Lieutenant Roy Clayton and Mr Ronald Stuewe (1984) used WSCRS depot maintenance data in a research effort to validate the process of using flying hours and PAA to allocate costs. Their analysis concentrated on USAF attack aircraft data from 1977 through 1983. They used linear regression on the WSCRS generated depot maintenance data broken out by WBS at the fleet level (e.g. bomber, attack, cargo, etc.). Their effort could not support the present method of allocating depot maintenance costs by flying hours and PAA (7:74).

In direct response to the 1985 USAF/ACC request, a thesis completed by Captain Patricia M. Larson (1986) also addressed the allocation problem and focused on the percentages in Table 1. However, in an effort to get more precise data, Larson used the entire WSCRS data base for each year and a unique computer assisted methodology to creat a "tailored" data base (vs the WSCRS generated depot maintenance data base as Clayton and Stuewe had used). This process is explained in more detail in Chapter 2. Using linear regression on USAF cargo aircraft data, she attempted

to create models for each WBS that estimated the proportion of depot maintenance costs that were inventory related and the proportion that were flying hour related. The proportions in Table 1 could not be verified and the models she developed are only applicable "for estimating depot maintenance costs and do not provide proportions of depot maintenance costs to flying hours and PAA" (18:92).

Specific Problem

The specific problem addressed by this thesis is twofold. First, is it reasonable to assume, based on prior studies and the work to be done in this thesis, that primary authorized aircraft (i.e. inventory) and flying hours (i.e. usage) are appropriate variables to use for factor development of Air Force depot maintenance cost factors? That is, are depot maintenance cost per flying hour and depot maintenance cost per primary authorized aircraft factors valid?

Second, can percentage allocations similar to those presented in Table 1 for WBS categories be validated through using:

a.) regresson analysis on fighter and cargo aircraft data from a different breakdown of the data system (i.e. Federal Supply Group (FSG) categories) from the WSCRS Recoverable Item Distribution Report?

b.) goal programming as an alternate modeling technique to cross check the regression analysis used in a.)?

c.) a linear programming formulation as an additional cross check on the results from a.) and b.)?

Overview of Research Approach

Linear regression was the primary statistical technique used to estimate depot maintenance costs in the Larson and Clayton and Stuewe studies. Neither study showed a significant relationship between the dependent variable, depot maintenance cost, and the two independent variables, PAA and FH.

Charnes, Cooper and Sueyoshi suggest that an alternative statistical methodology be used to cross-check study results when "important issues of policy are being addressed" (6:4). They used goal programming to check the results of an econometric study done on the breakup of the AT&T system. This research follows their lead and uses goal programming and linear programming as alternate techniques to cross-check regression results.

The data base that will be used in this research comes from the WSCRS system, and is called the Recoverable Item Distribution Report. This report categorizes depot maintenance costs by Federal Supply Group (FSG) vice WBS as used in the Clayton/Stuewe and Larson theses and is available for each of the years that WSCRS has been in existence. The Recoverable Item Distribution Report was not available when the Clayton/Stuewe study was done and was not

used by Larson because of her desire to create a "tailored" WSCRS data base.

Analyzing data at a lower level than the WBS categories--that is, at the Federal Supply Group (FSG) cost level using the same independent variables FH and PAA--was suggested in the Larson thesis. Because Clayton and Stuewe found no relationship between WBS and FH and PAA at the summary level, Larson felt a more detailed data base might reveal a relationship if any existed. There are several times as many FSG classifications than the eight WBS categories. For example, this proposed procedure could yield the following depot maintenance cost allocations for cargo aircraft:

Federal Supply Group	Nomenclature	(theoretical allocations of) FH	PAA
15	Aircraft and airframe structure components	80%	20%
26	Tires and tubes	70%	30%
41	Air conditioner and air circulation components	35%	65%

(18:22)

This proposed method of analysis is similar to the analysis approach for this study. Linear regression will be used to analyze fighter and cargo aircraft data available from the Recoverable Item Distribution Report. Additionally, goal programming and linear programming will be used as cross checks to the findings.

In summary, this thesis will attempt to verify whether using PAA and FH to allocate depot maintenance costs is valid and, concurrently, develop depot maintenance cost factors based on the results obtained.

Background

This section contains reviews of the Air Force three-level aircraft maintenance system, the Air Force depot maintenance system, and the management information system used to collect maintenance cost data.

Levels of Maintenance. There are three types of US Air Force aircraft maintenance: organizational, intermediate, and depot maintenance. Organizational maintenance is the most basic maintenance and is performed at the base or organizational level. It includes activities such as inspecting, servicing, and the replacement of parts, minor assemblies, etc. Intermediate maintenance is also performed at the base and consists of more involved activities such as calibration, repair or replacement of damaged or unserviceable parts, the manufacture of critical nonavailable parts, and providing technical assistance to using organizations. The third level, depot maintenance, is formally defined by DOD Directive 4151.16 as:

> ... maintenance [activities which] augment stocks of serviceable material and ... support Organizational Maintenance and Intermediate Maintenance activities by use of more extensive shop facilities, equipment, and personnel of higher technical skill than are available at the

> lower levels of maintenance. Its phases normally consist of inspection, test, repair, modification, alterations, modernization, conversion, overhaul, reclamation or rebuilding of parts, assemblies, subassemblies, components, equipment, end items,... manufacture of critical nonavailable parts and providing technical assistance to intermediate maintenance organizations, using and other activities.

"In other words, depots are needed when the maintenance complexity of a repair is beyond the capabilities of flight line units" (7:15).

Air Force Depot Maintenance System. Air Force depot maintenance activities are conducted by Air Force Logistics Command (AFLC) at five primary locations. A description of these locations and some of their major assignments follow. Ogden Air Logistics Center (ALC) is responsible for two aircraft (F-4 and F-16) and five engine systems (LR58, LR59, LR87, LR91, and RJ43) along with air munitions, and photographic and reconnaissance equipment. Oklahoma City ALC does repair work on seven aircraft (e.g. A-7D/K, B-1B, and B-52), 19 engine systems (e.g. J-57, F-101, and TF-33), aircraft instruments, and aircraft hydraulic systems. Sacramento ALC is responsible for 11 aircraft (e.g. A-10, C-121, EF/F/FB-111, F-5, and the ATF) and numerous communications-electronics equipment. San Antonio ALC's repair mission focuses on six aircraft (e.g. A-37A/B, C-5, C-9A, and C-131), 31 engine systems (e.g. J79, J85, TF34, TF39, and R2000), and electronic support equipment. Finally, Warner Robins ALC is assigned three aircraft

systems (C-130, C-141, and F-15), gunnery equipment, and airborne electronics (source:AF-ALC/XRXP). The aircraft maintenance performed at these depots can be organic (i.e. performed by military or DOD civilian personnel using government facilities), contract, or interservice.

Weapon System Cost Retrieval System (WSCRS). The data on the various depot maintenance operations performed by AFLC are recorded through a detailed network of thirty-one management information systems. The FSG cost data used for this thesis come from the Weapon System Cost Retrieval System (WSCRS) which is one of those data systems. WSCRS is the primary system used to report depot maintenance cost data within AFLC. WSCRS assembles data through interfacing primarily with five AFLC data collection systems. These are:

1. The D041, Recoverable Consumption Requirements System, which provides WSCRS with nomenclature, unit prices, number of condemnations, and the quantity of all stock items used for each Mission Design Series (MDS) (e.g. F-16A, C-130H, B-52G).

2. The G033J, Past Program Data System, "provides the actual flying hours and inventory months" (12:7) for each MDS.

3. The H036B, DMS, ASIF Cost Accounting Production Report, provides the annual depot maintenance costs (12:6-7).

4. The D097, Interchangeability/Substitution (I&S) Data Maintenance System provides parts stock numbers.

5. The D160, VAMOSC II--Weapon System Support Cost System furnishes costs summarized by work breakdown structure for each MDS.

The office of primary responsibility (OPR) for WSCRS is HQ AFLC Directorate of Cost (AFLC/ACC).

Recoverable Item Distribution Report. For this study, an alternative source of data from WSCRS called the Recoverable Item Distribution Report, will be used. The Recoverable Item Distribution Report is an alternative to Larson's data base, which is a consolidation of the entire detailed WSCRS data base into WBS categories. This annual report gives consolidated mission (e.g. cargo, attack, bomber, etc.) cost data for each fiscal year categorized by Federal Supply Group (FSG) and Federal Supply Class (FSC). Examples are shown in Table 2.

TABLE 2

EXAMPLES OF FEDERAL SUPPLY GROUP (FSG) CATEGORIES

FSG	Federal Supply Commodity Classification
10	Weapons
11	Nuclear Ordnance
12	Fire Control Equipment
13	Ammunition and Explosives
14	Guided missiles
15	Aircraft & Airframe Structural Components
16	Aircraft Components & Accessories
26	Tires and Tubes
28	Engines, Turbines & Components
29	Engine Accessories
30	Mechanical Power Transmission Equipment

Presently, there are 78 federal supply groups subdivided into 617 federal supply classes. For this study, costs will be evaluated at the group level:

> The Federal Supply Group (FSG) identifies, by title, the commodity area covered by classes within the group. Each class covers a relatively homogeneous area of commodities, in respect to their physical or performance characteristics, or in the respect that the items included therin are such as are usually requisitioned or issued together, or constitute a related grouping for suppy management purposes. (8:iii)

Scope of Study

1. Only data from the AFLC WSCRS depot maintenance cost data base are used in this study. Assumptions and limitations of this data are included in the Research Methodology chapter of this study.

2. Only cargo and fighter aircraft data included in WSCRS will be examined in this study.

3. This study will analyze aircraft depot maintenance costs at the mission level for the cargo and fighter mission categories for all aircraft in these mission categories.

Thesis Organization

This thesis is broken down into five chapters. This first chapter has identified the general and specific problem to be addressed in this study. Then, background information was presented on cost factor requirements and regulations, and on Air Force maintenance. This was followed by a discussion of the AFLC data collection

systems, and then the scope of the study was discussed. The second chapter is a review of literature that pertains to the issues raised in Chapter I. Chapter III is the methodology and provides the primary approaches to be used in this thesis for addressing the problem. The fourth chapter is the analysis and results of the proposed methodologies. This research concludes with Chapter V which contains the conclusions and recommendations.

II. Literature Review

Overview

This literature review begins with a review of the three most common cost estimating methods: analogy, grass roots (or engineering), and parametric methods. Reviewing these three methods provides an awareness that there are different techniques for the numerous types of situations that arise in the cost estimating environment. In the discussion on the parametric method, cost estimating relationships (or CERs) are introduced. This is followed in the next section by a more extensive look at CERs because of their importance and widespread use in the cost estimating environment. The ability to identify cost drivers and the development of CERs are key to effective cost estimation efforts.

Next is a definition of cost factors from the National Estimating Society dictionary, then a section on how cost factors are developed. The difference between a cost factor and a CER is presented, followed by a discussion on the use of cost factors to explain how they fit in to the cost estimating process.

In the last section, two Air Force Institute of Technology theses--one by Clayton and Stuewe, and one by Larson--will be reviewed. Through the use of the WSCRS data base, each of these studies has used a different approach in attempting to verify the current depot maintenance cost

allocation percentages and depot maintenance cost factor development using flying hours (FH) and primary authorized aircraft (PAA).

Cost Estimating Methods

A number of tools and techniques have been developed for use in estimating weapon system costs. In the past, characteristics such as weight and thrust have been used to estimate aircraft airframe and engine costs, respectively. However, cost estimators have continuously searched for other aircraft characteristics that (1) will provide consistently accurate estimates, (2) are logically related to cost, and (3) can easily be determined prior to actual design and development, thus allowing for trade-offs between cost and physical/performance characteristics (17:1).

The three most popular methods currently used for cost estimating are the analogy method, the grass roots (or engineered) method, and the parametric method. Determining the specific method to be used is normally governed by the time available for the estimating effort, the degree of system definition at the time of the analysis, the kind and amount of input available, and the level of detail required (27:7.3).

These three methods are described in the following paragraphs.

Analogy Method. When using the analogy method, the cost estimate of the new item is derived from the past costs of items that have similar or analogous characteristics. Contractor price quotations or prior prices are tested for reasonableness and allowances are made using adjustment factors (e.g. inflation) for the differences between the proposed item and analogous items. The data used for making analogous estimates is normally taken from historical records of recent procurements which include information on the specification, schedule, and the contracting environment in which the item was procured (4:6-7).

Applying the analogy method is appropriate when data from several similar items are available and when estimating time is limited. There are several disadvantages of this method. First, the analyst's judgment as to what is an analogous item must be relied upon (27:7.5). Thus the analyst must be completely knowledgeable about the system for which the cost estimate is being prepared. A second disadvantage is that adjustment factors used to account for differences are subjective. They are based on the analyst's judgment regarding the magnitude of the differences between the proposed item and the analogous past items used for comparison. Finally, analogy models tend to have limited usefulness with respect to design trade-off applications because costs are ordinarily computed as a function of parameters such as mean time between failures and

maintenance man-hours per flying hour. Costs are not related directly to performance and design parameters so the estimate cannot be used early in the conceptual phase when trade-offs relating to performance/design parameters are usually made (4:7).

Grass Roots (or Engineered) Method. Cost estimates using the grass roots method are based on extensive knowledge of the system's characteristics. The analyst is expected to have a detailed knowledge of the system, the production processes, and the production organization. The total project cost is the consolidation of estimates from each of the lower level components of the system or item (27:7.5).

The grass roots method is preferred if detailed cost data exists (27:7.6). However, detailed cost information, especially in DOD procurements, is not usually available early in the development process which makes this approach difficult to apply. Normally, by the time detailed information is available, many decisions have already been made and the choice among the various initial alternative systems has been reduced to only a few (4:8). Additionally, the grass roots method is generally more costly and time consuming than other available cost estimating techniques. For example, "one large aerospace firm judges that the use of this approach [on just an aircraft airframe] requires more than 4,000 separate estimates" (27:7.6).

Parametric Methods. Parametric methods involve using mathematical techniques (e.g. regression analysis) with parameters applied to aggregate historical data to develop an estimate formula (1:3-21). "Through curve-fitting techniques, system cost is related to a combination of system parameters such as physical dimensions, weight, maximum speed, etc." (4:8). The relationships are expressed in the form of mathematical equations and are referred to as cost estimating relationships (CERs are discussed in detail in the next section of this chapter). For example, in depot maintenance cost estimating, the dependent variable is cost while the independent variables might be the parameters flying hours and primary authorized aircraft.

Following is an explanation of the usefulness of parametric methods:

> If detailed cost data is not available, parametric cost estimating is preferred over other methods for at least three reasons: (1) CERs can be developed and used early in the preliminary design stages of RDT&E to study the effects of varying parameters on system cost, thus allowing cost comparisons of different alternative designs; (2) the relatioships developed can be used to obtain preliminary cost estimates before the details of design or O&S concepts are certain; (3) they require less input data than engineered models and can be more easily used for sensitivity or parametric analysis. (4:9)

The next section is a discussion on CERs which are the basis for the parametric methods commonly used in weapon system cost estimating.

Cost Estimating Relationships (CERs)

Future costs can be estimated by using the aggregate, historical data of similar systems or procedures to develop cost estimating relationships. Using CERs has been very useful in estimating costs from a top-down viewpoint. CERs attempt to define the relationship between the resources required to produce a system [or as in this study--to provide depot maintenance] and the physical, technical, performance, and/or hybrid characteristics of the system (20:20). For example, the costs of a proposed manned bomber can be estimated by using estimating relationships that express cost per aircraft as a function of variables expressing performance or physical characteristics, times the number of aircraft produced. Following is a general definition of a CER:

> A CER is an equation which attempts to define the relationship between the resource required to produce a system and the physical and/or performance characteristics of the system and/or the process required to produce the system. (20:20)

Estimating relationships exist in many different forms and numerous possible types may be useful to the analyst. In his book Cost Considerations in Systems Analysis, Fisher gives several fundamental points of CERs. They are included here to provide a basic framework for understanding CERs:

> 1. Estimating relationships are analytic devices which relate various categories of cost (either in dollars or physical units) to cost-generating or explanatory variables.

2. They may take numerous forms, ranging from informal rules of thumb or simple analogies to formal mathematical functions derived from statistical analyses of empirical data.

3. A most important step in the derivation of estimating relationships is to assemble and refine the data that constitute the empirical basis of the relationship to be developed. Typically, the raw data are at least partially in the wrong format for analytical purposes, have various irregularities and inconsistencies, and the like. Adjustments, therefore, almost always have to be made to ensure a reasonably consistent and comparable data base. No degree of sophistication in the use of advanced mathematical statistics can compensate very much for a seriously deficient data base.

4. Given the data base, any of a wide variety of techniques may be used to derive appropriate estimating relationships. The range extends all the way from unaided judgment and simple graphical procedures through complex statistical techniques. Here, considerable judgment must be exercised. The particular method used is strongly related to the nature of the problem, and particularly to the nature of the data base. For example, it usually does not make sense to try to fit a complicated multivariate function to a data base having a very small sample size, since it is easy to run out of degrees of freedom in such cases. Even with a relatively large data base, one must avoid mechanically running large numbers of correlation analyses on the computer to determine that combination of explanatory variables which maximizes the correlation coefficient... High correlation coefficients, in and of themselves, do not necessarily ensure statistically significant relationships.

5. Care must also be exercised in the use of estimating relationships. The user must have a good understanding of the data base and the procedures used in deriving the estimating relationship. Above all, he must exercise care in extrapolating beyond the range of experience (the sample) underlying the relationship. Scaling factors, for example, may have to be taken into account, especially when--as happens very often--we are estimating the costs of future equipments

or activities which are different from those of the past, present, and near future. (13:123-124)

The individual factors which are the basis of a CER are called the "cost drivers". It is the analyst's decision to identify which features are to be considered a cost driver. This process is one of the major tasks to be accomplished in developing a CER. Some examples of cost drivers are:

Characteristic	Cost drivers
Physical	weight, volume, length, number of parts, number of copies, and density
Technical parameters (factors that produce performance)	power requirements, engine thrust, turbine inlet temperature
Performance	flying hours, speed, range, accuracy, reliability
Hybrid variables	thrust to weight ratio, operating environment, system mission or function, technology level vs. state-of-the-art

Once the cost driver(s) (i.e. independent variable(s)) has been selected, a parametric method is applied to identify the relationship between the driver and how it impacts cost. For example, in his report "Development of Parametric Cost Models for Weapon Systems," J.P. Large used a data base of 14 aircraft engines to explain how three parameters (= cost drivers) are related to aircraft engine cost. Following is the actual equation with an explanation following:

$$COST = A_1 + A_2TIT - A_3MQT + A_4S_{AB}$$

The As in the equation are the regression coefficients. A_1 is the Y intercept of the regression line and will have meaning if the model includes X=0, otherwise, A_1 does not have any particular meaning as a separate term in the regression model. A_2, A_3, and A_4 represent the means of the probability distribution of cost per unit increase in TIT, MQT and S_{AB}, respectively (24:33).

> The first independent variable [i.e. TIT] says that turbine inlet temperature governs engine performance and dictates engine complexity. The second says that the development effort required [MQT] to achieve a specific turbine inlet temperature reduces with time. The third stipulates that afterburning engines [S_{AB}] cost more to develop because of the additional design and testing required.... Regression analysis was then used to determine whether the three hypotheses could be justified, and a useful parametric cost model was obtained. (16:26)

This simplified discussion of cost estimating methods and CERs provides the background for understanding the cost estimating process. Cost factors, which are intertwined with the cost estimating process and are a type of parametric estimating methodology are now discussed in detail.

Cost Factor

The National Estimating Society (NES) Dictionary defines a cost factor as:

> A cost estimating relationship (CER) in which the cost is directly proportional to a single independent variable. A brief arithmetic expression wherein cost is determined by application of a factor such as a percent, e.g.,

> initial spares percent, general and administrative percentage, or a ratio as in pay and allowance cost per man per year. (23:41)

The next section discusses cost factor development for use in the estimating process.

<u>Cost Factor Development</u>. A basic assumption of the development of cost factors is that there is a direct relationship between the cost and the planning factor (e.g. FH, PAA, etc.). This is normally based on data over a long period of time, for example, POL per flying hour factors.

> Currently, cost factors are being developed by collecting data on both the cost, Y, to be estimated and the planning factor, X, to be used in estimating the cost. The means of both distributions are calculated. The quotient of these two means, b, is then used as the cost factor. (26:2-3)

$$\frac{\bar{Y}}{\bar{X}} = b$$

where: $\bar{Y}$ = mean of the costs

$\bar{X}$ = mean of the planning factor

This makes it possible to get a cost estimate by simply multiplying the cost factor (b) by the planning factor (X) expressed as the equation:

$$Y = bX$$

This technique is valid

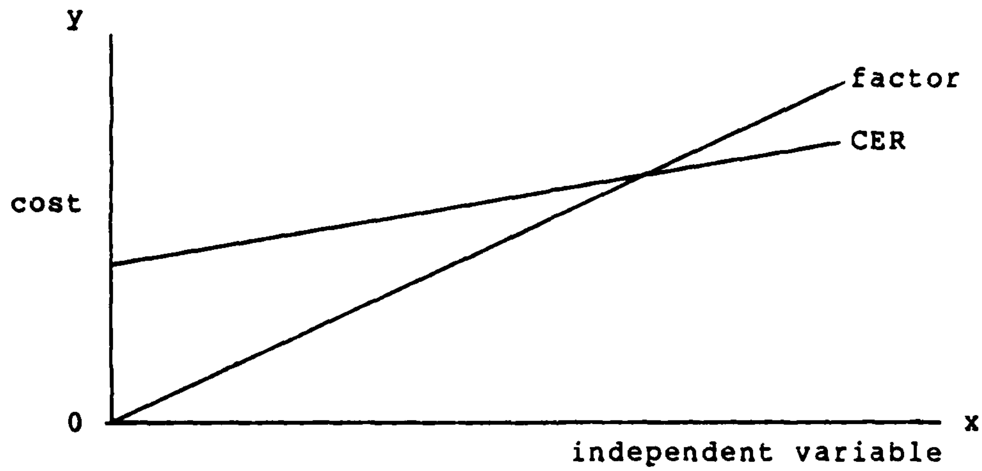
> assuming that prior knowledge allows one to make the assumption that the line representing this relationship does in fact go through the origin. In other words, the intercept [a] of the standard equation for the straight line,
>
> $$Y = a + bX$$
>
> is zero. (26:3)

To clarify the difference between a cost factor and a CER, Mr Richard Murphy explains that a cost factor is a CER under certain conditions:

(1) There is a linear relationship, and the

(2) Y intercept goes through 0.

An example of a cost factor and CER is shown in Figure 1:



(21)

Figure 1. Graphical Representation of a Cost Factor and a CER

Use of Cost Factors. As discussed in Chapter I, AFR 173-13 contains the cost factors used in the DOD's weapon system acquisition process and the Planning, Programming, & Budgeting System (PPBS). These cost factors are the basis for the procedures that are used to develop the cost estimates for producing new systems, modifying existing systems, or supporting systems. Another reason these factors are important is because Congress and the public

frequently evaluate how well the DOD is performing by comparing actual cost to estimated cost.

Cost factors are used as "a statement of the relationship between two or more related elements that can be applied in estimating and analyzing future relationships among similar elements (26:1). Cost factors are valuable in that they can save large amounts of time in creating an estimate--"a cost factor makes it possible to estimate a highly aggregated future cost, e.g. equipment maintenance costs, without a detailed identification and costing of each of the specific resource inputs to this future cost" (15:3). This means that much time is saved in accumulating data and information by using an aggregated, generalized cost factor. "In a short period of time, an analyst can estimate future expenditures that would require days or even longer by direct measurement of all the elements in the study" (26:1).

Using cost factors can also provide a more accurate and reliable estimate as compared to direct measurement as long as the cost factors are developed from a "wide-coverage, carefully documented, objective, after-the-fact analysis of representative available data" (15:3). Direct measurements are often the result of fragmentary and hastily prepared data that does not take into consideration all the available historical information. Additionally, cost factors can be more accurate when adequate direct measurements of total life-cycle costs are not available as is true in the

advanced-planning stage when the physical and performance characteristics have not been identified in detail.

It is important, though, for the analyst to make use of every available tool--direct measurement as well as cost factoring--that is at his or her disposal. If time constraints permit, one technique can be used to spot-check the other. However, the analyst, "if confronted with a choice ... will [frequently] find that the use of cost factors not only reduces the time required to complete an estimate, but also provides a more reliable, accurate estimate (15:3).

Depot Maintenance Cost Allocation Studies Using WSCRS

As discussed in Chapter I, the Weapon System Cost Retrieval System (WSCRS) is the primary source of all Air Force depot maintenance cost data. The system monitors depot maintenance work done at the Air Logistics Centers and is the most inclusive and current source of data. AFLC Manual 173-264 explains the usefulness of WSCRS data:

> In the past, cost data collected were often inconsistent from project to project because of different data sources, different cost definitions (obligations vs expenditures), and different methods of allocating costs to weapon systems. The development of WSCRS alleviated these problems for cost analysts by providing one consistent source of historic cost information and by retaining the information in cost data bases for easy access and timely retrieval. (12:4)

Following are reviews of two recent AFIT theses that have utilized the WSCRS data base.

Clayton and Stuewe. In 1984, an Air Force Institute of Technology thesis by First Lieutenant Roy Clayton and Mr. Ron Stuewe (7) addressed the question of how aircraft depot maintenance costs should be classified. They referenced the current percentages used in depot maintenance cost allocation that are found in Table 1. Their study cited three shortcomings of this allocation:

> 1. The creation of the current percentages employed depot maintenance cost data prior to the establishment of the WSCRS data base. This data may not represent the costs associated with present aircraft technology levels.
>
> 2. The percentages used are common for all aircraft in splitting WBS costs, disregarding differences in aircraft systems. WBS cost percentages could change with respect to aircraft mission or type. For example, cargo aircraft operate continually at a constant performance level in transporting men and materials, while fighter aircraft fly less frequently at a heightened performance level.
>
> 3. The percentages are nonreproducable. Since the prior rationale for this split cannot be located, the percentage breakout cannot be analyzed and/or modified to accommodate changes. (7:7-8) [Chapter I includes information that these allocations came from an undated and unsigned paper--approximately 1974--found at HQ USAF/ACC.]

Their work attempted to validate the existing breakout by WBS categories and FH and PAA, or if not valid, to improve the percentages currently used.

They used the WBS categories for Air Force aircraft as reported by WSCRS. This data is obtained from the data gathering system which operates on the Cyber computer system located at Headquarters AFLC. Annually, each contractor and

AFLC maintenance depot provides a detailed record of accumulated cost data. This is called feeder information and "consists of individual cost elements that are continually tracked and reported by aircraft weapon system or aircraft components for a given fiscal year" (7:18). At this point the Cyber computer compiles the data (through interfacing with the five AFLC data collection systems outlined in Chapter I), adjusts, calculates, and allocates it into the WSCRS standardized WBS categories shown in Table 1.

Clayton and Stuewe applied multiple linear regression and delta analysis techniques at both the mission (e.g. attack) and fleet (e.g. A-7) levels of aggregation. Their analysis focused on attack aircraft data. The multiple linear regression results using FH and PAA to explain WBS costs could not provide conclusive evidence of a strong relationship (7:42). In other words, the independent variables FH and PAA could not be shown statistically to drive WBS costs. Another problem that surfaced in their regression analysis was multicollinearity, that is, a strong relationship between the independent variables FH and PAA. The delta analysis results of their study also concluded the lack of a relationship between cost, FH, and PAA. Additionally, "the detail provided by delta analysis [i.e. a method analyzing the changes in variables from year to year]

also demonstrated the strong presence of multicollinearity" (7:53-54).

Therefore, Clayton and Stuewe concluded that "each of the applied techniques resulted in a weak relationship between the aircraft variables (flying hours and PAA) and depot maintenance WBS costs" (7:31). Because of this weak relationship, they further stated that "any method of prorating depot maintenance WBS costs to develop cost factors based solely on flying hours and inventory explanatory variables is not appropriate" (7:74).

Clayton and Stuewe address the present OSD requirement to use of FH and PAA as allocation bases despite the weak relationship. They comment that there is "intuitive appeal" in selecting flying hours and aircraft inventory as factors that influence depot maintenance costs because if there were no aircraft there would be no depot maintenance requirements and "if the aircraft are not flown, the depot maintenance requirements would amount to only preservation" (7:79).

Larson. Captain Patricia Larson in her 1986 Air Force Institute of Technology thesis also focused on the WBS cost allocation percentages found in Table 1. Her research effort was in direct response to the 1985 USAF/ACC request for a scientifically verifiable allocation of depot maintenance costs by FH and PAA. Larson prepared a data base using tapes provided by AFLC/ACC with the entire WSCRS data base for FY77 through FY85. The AFIT Classroom Support

Computer (CSC) was used to develop--through several computer programs and steps--and provide an "analyst's data base" (18:29-32). Thus, instead of using the data already summarized by WSCRS for analysis, required data could be extracted for the analyst's specific need. Ultimately, Larson extracted and analyzed cargo aircraft data by fleet total and WBS categories (not FSG).

Larson applied multiple linear regression techniques to the cargo aircraft data and results showed that in the cargo summary data that "the independent variable, flying hours, appears to be the sole significant variable" (18:57). When broken out into the WBS categories, regression analysis showed a relationship between depot maintenance costs and FH or PAA in only three of the eight categories. As discovered in the Clayton and Stuewe thesis, no significant basis for the depot maintenance allocation percentages in Table 1 was found: "the task of finding appropriate allocations of depot maintenance costs to flying hours and PAA is not solved" (18:63).

Her analysis also showed the multicollinearity between FH and PAA that the Clayton and Stuewe thesis had found. Ridge regression (a technique used when collinearity is suspected between two or more independent variables), was applied to the data in her study. Again, no appropriate basis for depot maintenance costs to be allocated as in Table 1 was found.

Since the beginning of Larson's research, an output report from the WSCRS system is available that reports depot maintenance costs in the FSG format she suggested be analyzed. This report, called the Recoverable Item Distribution Report will be the data base used in this research as discussed in Chapter I.

Summary

This chapter has outlined some important aspects concerning cost estimates. First, the three most common cost estimating methods were introduced to show that there are several alternatives to the cost analyst when faced with a particular estimating environment. Cost estimating relationships were then discussed in detail to outline the importance of determining an appropriate cost driver or drivers in cost estimating. Next, a cost factor was defined and the process of cost factor development was discussed. How costs are used was then detailed to explain how they fit in to the cost estimating process--especially in their ability to save time in producing an estimate. Finally, two AFIT theses that have evaluated the current requirement to allocate depot maintenance costs according to specified variables and percentages were reviewed. Results of these studies are that the current variables (i.e. FH and PAA) and percentages used do not effectively estimate depot maintenance costs.

III. Research Method

Overview

This section constructs the procedures followed to test the research questions: 1) is it reasonable to assume that primary authorized aircraft and flying hours are appropriate variables to use for development of Air Force depot maintenance cost factors and, 2) can percentage allocations similar to those presented in Table 1 for WBS categories be validated for FSG categories through using a.) regression analysis on fighter and cargo aircraft data from the Recoverable Item Distribution Report, b.) using goal programming as an alternate modeling technique to cross check the regression analysis used in a.), and c.) a linear programming formulation as an additional cross check on the results from a.) and b.).

This analysis uses data from a new WSCRS output report --the Recoverable Item Distribution Report. As discussed in Chapter I, the Recoverable Item Distribution Report gives cost totals by Federal Supply Group categories vice WBS categories that have been used in the Clayton/Stuewe and Larson theses. Fighter and cargo aircraft data from this report will be analyzed. The data will be analyzed using linear regression, goal programming, and linear programming techniques. Goal programming and linear programming will provide an opportunity to cross-check and further verify results from regression analysis.

This chapter is structured in the following manner. First, there will be a discussion of assumptions and limitations followed by an explanation of the data base. Next, the procedures used to adjust the depot maintenance cost data for inflation will be discussed, and finally, the three analysis procedures used to examine the data are presented.

Assumptions/Limitations

Data used in the WSCRS--and the Recoverable Item Distribution Report as an output of WSCRS--includes several assumptions and limitations which will be explained here. A more extensive discussion of limitations and constraints is included in AFLCM 173-264. As mentioned in the scope of study in Chapter I, only fighter and cargo aircraft data will be used and the data are examined at the mission (e.g., attack, cargo, bomber, etc.) level versus the design (e.g. A-7, C-130, B-52, etc) or series (e.g. A-7D, C-130E, B-52G, etc) level.

1. Reparable items are sometimes repaired in batches at the depot, instead of individually, because repairing in batches is more economical. If an item is sent to the depot in one fiscal year, placed in a batch and fixed the following fiscal year, its costs are reported in the fiscal year in which it is repaired instead of the year in which it malfunctions. Consequently, reported costs may be high

in one year and low in another (12:15,76). No research has been done on the exact impact of batch processing on cost data. Thus, for this research it is assumed the impact is the same from year to year and therefore does not impact the analysis.

2. WSCRS allocates costs which are common to more than one MDS to each MDS. Thus, an item from a particular aircraft sent to the depot for repair may not be the same item that is returned to that aircraft. The costs for common items repaired are not specifically attributed to a particular MDS, and must be proportionally allocated. These allocations are based on FH and PAA. This is of concern to the validity in using the WSCRS' costs for this study. Deleting as well as including these costs can skew the data. Allocations of costs within the fleet will not affect this study because this study is evaluating the data at the mission level. For example:

> $10,000 in depot maintenance cost is performed on an air conditioning unit found in the C-5A, C-5B, C-135A, and C-135B. The allocation of the $10,000 by PAA will not affect this study because the entire $10,000 will be alocated to cargo. However, if the air conditioning unit is also used in the B-52G and B-52H, the allocation by PAA may skew this study since the $10,000 will be split between cargo and bomber [aircraft] based on the number of primary authorized aircraft. (18:27)

3. WSCRS contains actual expenditures vice using standard costs of all depot maintenance costs. (An exception is ICS/CLS costs which are the obligations from the contracts) (12:8).

4. WSCRS previously used an inventory number equivalent to total active inventory instead of primary authorized aircraft (PAA). HQ USAF/ACC directed AFLC/ACC to change WSCRS to use PAA in July 1984 (5). Using PAA meets the requirements for developing budget and life cycle cost factors, and for using the cost factors in cost studies and the budget process. AFLC/ACC manually completed this change in June 1986, and is currently updating the WSCRS historical data base. This study uses the corrected PAA quantities obtained from HQ AFLC/ACC.

Recoverable Item Distribution Report Data Base

This report is a new WSCRS output report (first issued in 1985) that is created annually and reports cost data in then-year dollars. The report has been generated for each year back to FY77. Therefore, Recoverable Item Distribution Report data for ten years, from FY77 through FY86 are available and analyzed in this research. The data were obtained from microfiche copies supplied by AFLC/ACC. Hardcopies were created from the microfiche and data were transferred to computer manually.

The Recoverable Item Distribution Report is generated from the WSCRS Detail Data Base which "contains cost information by fiscal year for each MDS" (12:13). From this data base "Type "1" and Type "2" records are used.

Following are definitions of these two data bases and paragraph (2) contains a limitation of the data used:

> (1) The NSN Records (Type "1") contain depot maintenance and condemnation exchangeable item costs identified to a national stock number (NSN).... These records contain the repair costs for management of items subject to repair (MISTR) items.
>
> (2) The FSC Records (Type "2") contain exchangeable item costs identified to an FSC. Depot maintenance repair costs identified to Technical Order Compliance (TOC) kits, part numbers, noncataloged, locally purchased, or locally manufactured items can be identified as weapon system costs, but they can't be related to a specific weapon system because of limited cross-reference information. Therefore, in preference to excluding these costs, the total cost by FSC is allocated over all applicable weapon systems. (12:13)

On the report, item quantities and costs are summarized and displayed by FSC, subtotaled by FSG (a homogeneous group of related FSCs (2:288)), and totaled for the entire fleet (i.e. fighter, cargo, etc.). For this research, data in then-year dollars are extracted and indexed to 1986 dollars as described in the following section.

Economic Escalation

U.S. Air Force cost analysis program procedures require cost data to be escalated using OSD inflation indices to account for inflation. AFR 173-2, Cost Analysis Economic Escalation, provides the rationale for this procedure as stated below:

> Economic escalation data resulting from inflation provides the best cost estimate possible for funds that are to be expended in a particular year, consistent with the economic assumptions provided by the OMB to the Office of the Assistant Secretary of Defense, Comptroller, OASD(C). Economic escalation indices also make possible comparisons of costs in different years for the Air Force cost analysis program, according to AFR 173-1. (9:1)

Therefore, cost data used in this research are converted to constant FY86 dollars using OSD Raw Inflation Indices as of 29 December 1986. The inflation indices used are shown in Table 3.

TABLE 3

OPERATIONS AND MAINTENANCE
RAW INFLATION INDICES

Fiscal Year	Index
77	.547
78	.590
79	.644
80	.706
81	.790
82	.863
83	.905
84	.940
85	.972
86	1.000

Examination of the Data

This section will discuss the three analysis procedures--linear regression, goal programming, and linear programming--that are used in this research.

Linear Regression. Linear regression procedures are commonly used and well understood in cost estimating. For this study, regression analysis will provide statistical data for analysis. These statistics will provide a basis for evaluating the ability of the independent variables FH and PAA to predict depot maintenance cost and the validity of the resulting regression models.

Regression analysis is defined as "a statistical tool that utilizes the relation between two or more quantitative variables so that one variable can be predicted from the other or others" (24:23). Least-squares-best-fit regression analysis, which is used in this research, fits a line to the observed data so as to minimize the sum of the squared deviations between the observed data and the fitted line (24:10).

For this research, depot maintenance cost categorized by FSG is the dependent variable in the regression model. The independent variables are pre-determined to be flying hours (FH) and primary authorized aircraft (PAA). This is per OSD CAIG guidance, AFR 173-4 and AFR 173-13 as explained in Chapter I.

The linear regression models that will be used to analyze the data are:

Independent Variable(s)	Model
(1) FH only:	$B_0 + B_1FH = Cost$
(2) PAA only:	$B_0 + B_2PAA = Cost$
(3) FH and PAA:	$B_0 + B_1FH + B_2PAA = Cost$

where: B_0 = Y-intercept of regression line
B_1 = coefficient for FH to be determined by the regression model
FH = flying hours
B_2 = coefficient for PAA to be determined by the regression model
PAA = primary authorized aircraft
Cost = depot maintenance cost

Analysis of the regression results will include examining the model's coefficient of determination (R^2), F value and associated probability- or p-value (= significance level), and the t-statistic(s) and p-value(s) for the model's intercept and independent variable(s) coefficient(s). These tests will aid in determining the strength of the model in predicting depot maintenance costs. Because of the small sample size (10 observations or less) of each FSG cost, this study will not test for normality or heteroscedasticity. Each test will now be explained.

The coefficient of determination (R^2) measures how well the independent variables account for the variations in the actual cost data. It can be written as:

$$R^2 = \frac{\text{Explained Variance}}{\text{Total Variance}}$$

The value of R^2 lies between zero and one and the "closer it is to 1, the greater is ... the degree of linear association between [the independent variable(s) and dependent variable]" (24:97). Based on a prior R^2 analysis

performed in an unpublished analysis of Army turboshaft engine costs (22) and a suggestion by Mr Richard Murphy (AFIT instructor), for this research, the R^2 is considered significant at the .80 level or higher. This indicates an effective explanatory ability of the independent variable(s).

The F-ratio from the analysis of variance table is also evaluated to determine if the overall estimating model is statistically significant. That is, this test determines whether it is probable that all of the model's coefficients are actually zero. It is reasonable to conclude that if an F p-value is significant at the 90+% level of confidence, the overall relationship is statistically significant. In other words, the higher the calculated F-value is, the better the model may be (24:86-87, 92-94).

The t-statistic will also be evaluated to determine if the particular cost driver (i.e. FH or PAA) is making a significant contribution to the overall equation. A coefficient that is not significantly different from zero will cause that particular variable to drop out of the model because there is no linear relationship between that independent variable and the dependent variable (24:67-68). It would be reasonable to conclude that a variable is making a significant contribution if its corresponding t-statistic is significant at the 90+% level of confidence.

Collinearity will also be tested for. An explanation of collinearity is that

> when independent variables are correlated,... a regression coefficient does not reflect any inherent effect of the particular independent variable on the dependent variable but only a marginal or partial effect...(24:277)

The three methods that will be used to detect the presence of multicollinearity are:

> 1. Nonsignificant results in individual tests [t-test] on the regression coefficients for important independent variables.
>
> 2. Large changes in the estimated regression coefficients when a variable is added or deleted.
>
> 3. Estimated regression coefficients with an algebraic sign that is the opposite of that expected from theoretical considerations or prior experience. (24:390)

Allocation Models. The resultant regression model can be used to develop percentages by FSG for allocating depot maintenance costs in the following manner. First, if the "best" model is one that has a single independent variable, either FH or PAA, then the allocation would be 100% for the model's independent variable.

Second, if the "best" regression model is one which includes both FH and PAA (model (3)), then there are two possible approaches. If the t-test for the intercept in the regression model is insignificant, the intercept can be dropped from the model since it can be assumed that the y-intercept is zero. The following formula can then be used to determine a percentage allocation:

$$(4) \quad FH: \frac{B_1FH}{B_1FH + B_2PAA} \qquad PAA: \frac{B_2PAA}{B_1FH + B_2PAA}$$

If the y-intercept is significant based on t-test results, the intercept must be considered in creating allocations for FH and PAA. This can be done by developing an additional regression model by "forcing" a new best fit line through the origin. This new model is:

$$(5) \quad B_1FH + B_2PAA = Cost$$

Models (3) and (5) provide the same solution at their point of intersection. Thus, data from model (5) can be used in equation (4) to determine allocation percentages for those specific values of FH and PAA at this point of intersection. Note that these allocation percentages are valid only for these specific values of FH and PAA. However, a range of values for the independent variables where the allocation percentages might be acceptable can be computed. This can be done by determining a small, acceptable variance, say 10%, for the dependent variable (= depot maintenance cost) which then can be translated into a range of values for the independent variables. A two-dimensional representation of this concept is shown in Figure 2.

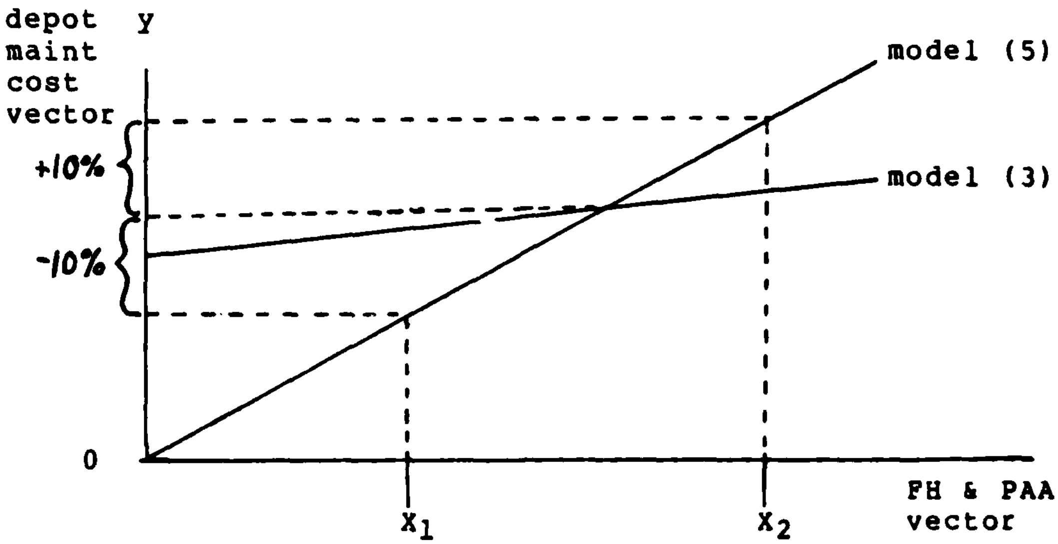


Figure 2. Graphical Representation of Original Regression Model and "Forced" Zero Intercept Model

In summary, regression analysis will be used to provide the data necessary to evaluate FH and PAA's ability to predict fighter and cargo depot maintenance costs and correspondingly, develop allocation percentages for depot maintenance costs. Least squares best fit regression's popularity in cost estimating makes it an effective tool for the purpose of this study. Another mathematical tool--goal programming--will also be used to evaluate the data, and is discussed next.

Goal Programming. Goal programming analysis will be used to cross-check results of regression analysis for this study. This approach was used in a recent study to evaluate another study which recommended the breakup of the AT&T system:

The goal programming/constrained regressions as reported in [the evaluation of the study] were, in fact, undertaken as a methodological cross-check on the results obtained [in a previous study] and it was this alternate methodology that led to the discovery of the data deficiencies, when our linear programming codes kept reporting "no solution." (6:6)

Goal programming is described as:

a procedure for handling multiple-objective situations within the general framework of linear programming. Each objective is viewed as a 'goal'. Then, given the usual resource limitations or constraints, the manager attempts to develop decisions that provide the 'best' solution in terms of coming as close as possible to reaching all goals. (3:213)

Additionally:

Goal programming greatly enhances the flexibility of linear programming as it allows the inclusion of conflicting objectives while still yielding a solution that is optimal with respect to the decision maker's specification of goal priorities. (19:254)

In order to perform goal programming modeling for depot maintenance costs, terminology must be explained and the model developed. This is accomplished with an explanation of goal programming terms from the book Linear Programming in Single- & Multiple-Objective Systems by James P. Ignizio, and how they relate to the particular model used in this research:

OBJECTIVE. An objective is a relatively general statement (in narrative or quantitative terms) that reflects the desires of the decision maker. For example, one may wish to "maximize profit" or "minimize labor turnover" or "wipe out poverty." (14:376)

In this study's model, the objective will be to minimize the deviations from yearly depot maintenance cost by FSG. An explanation of deviation variables follows.

> GOAL DEVIATION. ... The difference between what we accomplish and what we aspire to is the deviation from our goal. In all but trivial problems ..., we shall encounter deviations from our goals. Note that a deviation can represent over- as well as underachievement of a goal. (14:376)

Goal deviations are expressed using "deviation variables." There are two deviation variables for each of the ten years of data, a deviation plus variable (d^+) and a deviation minus variable (d^-). These represent the over or underachievement of using FH and PAA as independent variables to predict cost.

> GOAL. An objective [or constraint for goal programming] in conjunction with an aspiration level is termed a goal. For example, we may wish to "achieve at least X units of profit" or "reduce the rate of inflation by Y percent." (14:376)

The goals--or objectives--in a goal programming model are constraints and the objective is to come as close as possible to these goals. The goals are targets to be attained but with overages and underages permitted.

Based on these explanations, the general goal programming model that is used is shown as follows:

$$\text{Minimize:} \quad d^+_{77} + d^-_{77} + d^+_{78} + d^-_{78} \ldots + d^+_{86} + d^-_{86}$$

$$\begin{array}{ll} \text{Subject to:} & B_0 + B_1FH_{77} + B_2PAA_{77} - d^+_{77} + d^-_{77} = Cost_{77} \\ & B_0 + B_1FH_{78} + B_2PAA_{78} - d^+_{78} + d^-_{78} = Cost_{78} \\ & \vdots \\ & B_0 + B_1FH_{86} + B_2PAA_{86} - d^+_{86} + d^-_{86} = Cost_{86} \end{array}$$

where: B_0 = intercept to be determined by the model
B_1 = coefficient for FH to be determined by the model
$FH_{77}-FH_{86}$ = flying hours for each year
B_2 = coefficient for PAA to be determined by the model
$PAA_{77}-PAA_{86}$ = primary authorized aircraft for each year
$Cost_{77}-Cost_{86}$ = depot maintenance cost for each year

The results are examined to determine the extent to which each independent variable was brought into the model to explain cost. From this analysis, goal programming results are compared to regression results as to what value each gave to the coefficient for the independent variables FH and PAA. For intercept values assigned by goal programming, a "forced" zero intercept line and a range will be developed. The procedure for this is the same as discussed in the regression portion of this chapter. The coefficients are then changed into percentages using the following formulas:

$$(6) \quad FH: \frac{B_1 FH_{xx}}{B_1 FH_{xx} + B_2 PAA_{xx}} \qquad PAA: \frac{B_2 PAA_{xx}}{B_1 FH_{xx} + B_2 PAA_{xx}}$$

Here the "xx" subscript indicates the year for which the allocation percentages are being computed. Results are the percentage allocation of depot maintenance cost per FH and cost per PAA and these can be compared to regression results.

A third approach--linear programming--will be used to evaluate the data and is discussed next.

Linear Programming. Linear programming is defined as "a mathematical programming model in which the objective function and the restrictions on resources can be expressed as a system of linear equalities and/or inequalities" (19:26). General linear programming characteristics are discussed in the goal programming section above (e.g. objective and goal) since goal programming is a multi-objective extension of linear programming and formulation is done in a manner similar to linear programming (19:254).

In the goal programming model discussed above, the objective is to minimize the deviation variables. In this case, a more basic approach is used. Cost is the resource that the objective function seeks to minimize. The objective function and constraints of the linear programming model are formulated as shown below:

Minimize: $B_1FH_{86} + B_2PAA_{86}$

Subject to:

$$\begin{array}{l} B_1FH_{77} + B_2PAA_{77} >= Cost_{77} \\ B_1FH_{78} + B_2PAA_{78} >= Cost_{78} \\ \quad \vdots \\ B_1FH_{85} + B_2PAA_{85} >= Cost_{85} \end{array}$$

where: B_1 = coefficient for FH which represents a cost per FH

FH_{77}-FH_{85} = flying hours for each year

B_2 = coefficient for PAA which represents a cost per PAA

PAA_{77}-PAA_{85} = primary authorized aircraft for each year

$Cost_{77}$-$Cost_{85}$ = depot maintenance cost for each year

Note that the objective function must minimize cost for a particular year. Thus, FY86 data are used in the objective function.

Using analysis similar to that for goal programming, results are examined to determine the extent to which each independent variable explains cost. From these results allocation percentages of FH and PAA will be derived based on the resulting coefficients. Similar to the goal programming analysis above, the following formulas are used.

$$\text{FH:} \quad \frac{B_1 FH_{86}}{B_1 FH_{86} + B_2 PAA_{86}} \qquad \text{PAA:} \quad \frac{B_2 PAA_{86}}{B_1 FH_{xx} + B_2 PAA_{86}}$$

These percentages will then be compared with regression and goal programming results of percentage allocations to FH and PAA.

Conclusion

In conclusion, data from a WSCRS output called the Recoverable Item Distribution Report is analyzed using regression, goal programming, and linear programming. The primary purpose is to attempt to determine the validity of FH and PAA to predict depot maintenance cost and to develop cost per FH and cost per PAA allocation percentages. Regression is used because it is a popular and well

understood tool in the cost estimating community. Goal programming and linear programming are used to cross-check the results obtained in the regression analysis and to provide an alternate perspective to analyze the data.

IV. Analysis

This chapter describes the results and analysis of procedures outlined in the previous chapter. Included here is the data base used, and the results and analysis of three approaches: linear regression, goal programming, and linear programming.

Data Base

The depot maintenance cost data used for this study is taken from the WSCRS output Recoverable Item Distribution Report. Cost data for ten years, FY77-FY86, were extracted for the fighter and cargo total category (i.e. total weapon system) and also for each individual FSG within each of the fighter and cargo categories. Within the fighter aircraft category there are 24 individual FSGs, and the cargo aircraft category contains 28 individual FSGs. Flying hour (FH) data comes directly from the Recoverable Item Distribution Report and PAA data comes from AFLC/ACC.

Table 4 contains a sample of the fighter aircraft data used and Table 5 contains a sample of the data used for cargo aircraft. Complete data for all FSGs are contained in Appendices A & B. Data is in raw, or then-year, dollars on the top half of each page and the same data--converted to 1986 dollars by using the process described in the previous chapter--is at the bottom half of each page. To read these two tables, notice that each fiscal year (FY77-

FY86) is designated in the far left column and FH, PAA, and each individual FSG is defined at the top of each column. Start at the fiscal year of data desired and read across to the right until intersecting the desired FH, PAA, or FSG column. FH, PAA or the dollar amount is found at this intersection.

TABLE 4

SELECTED FIGHTER AIRCRAFT DATA IN THEN YEAR AND 1986 DOLLARS

WSCRS FIGHTER aircraft data in THEN YEAR DOLLARS by title and FSG #.
(N/S=not shown on Recoverable Item Distribution Report)

Year	FH	PAA	Photo Equip 67	Comm Dtec & Rad Eqp 58	Compnts & Accsories 16	Elec Pwr Equip 61	Wire/Engns/Turb & Compnts 28
77	762711	3180	0	23744503	21096303	2378023	42614940
78	737313	3250	3026294	26381903	27914203	3038235	52364604
79	737376	3223	2711003	30325152	29805132	3141529	61857068
80	704838	3091	2852425	30285923	30684668	3578660	86486363
81	731847	3101	3164694	56001229	40647131	4120565	76360541
82	775254	3095	4541440	67427374	50701308	4982572	109743303
83	822056	3182	5571894	67696572	60773734	5548663	142988208
84	871384	3222	6836888	91669054	77795956	7826732	195558332
85	884004	3287	6575598	91492153	68068064	7558261	210471391
86	897359	3273	8158480	97432178	75145729	7466379	185927955

WSCRS FIGHTER aircraft data in 1986 DOLLARS by title and FSG #.
(HQ USAF/ACCE Raw Inflation Indices issued 29 December 1986)

Year	FH	PAA	Photo Equip 67	Comm Dtec & Rad Eqp 58	Compnts & Accsories 16	Elec Pwr Equip 61	Wire/Engns/Turb & Compnts 28
77	762711	3180	0	43408598	38567282	4347391	77906654
78	737313	3250	5129312	44715090	47312208	5149551	88753566
79	737376	3223	4209632	47088745	46281261	4878151	96051348
80	704838	3091	4040262	42897908	43462703	5068924	122501931
81	731847	3101	4005942	70887632	51452065	5215905	96658913
82	775254	3095	5262387	78131372	58750067	5773548	127164893
83	822056	3182	6156789	74802842	67153297	6131119	157998020
84	871384	3222	7273285	97520270	82761655	8326311	208040779
85	884004	3287	6765019	94127729	70028872	7775989	216534353
86	897359	3273	8158480	97432178	75145729	7466379	185927955

TABLE 5

SELECTED CARGO AIRCRAFT DATA
IN THEN YEAR AND 1986 DOLLARS

WSCRS CARGO aircraft data in THEN YEAR DOLLARS by title and FSG #.
(N/S=not shown on Recoverable Item Distribution Report)

Year	FH	PAA	Structrl Compnts 15	Compnts & Accsories 16	Valves 48	Engine Accsories 29	Elec Wire/ Pwr Equip 61
77	929407	1702	15703988	28435591	2236711	15033751	3028484
78	959304	1702	28120659	41002748	3580416	19824507	4178572
79	960295	1673	29795546	42406680	3540144	27346572	5102665
80	945685	1684	30687012	43739134	4340774	23964232	5172974
81	1000591	1762	50532308	55962315	5739561	32756098	5848896
82	1014179	1798	55731097	68025564	6814460	39128572	6813043
83	1027874	1801	70600561	82607341	8121131	54187188	7438610
84	1044108	1825	87407841	88754351	10035295	59292598	8265886
85	1054457	1853	88540980	83127805	8786992	54169649	8306204
86	1042321	1900	98069946	82002976	8319797	49458822	8101808

WSCRS CARGO aircraft data in 1986 DOLLARS by title and FSG #.
(HQ USAF/ACCE Raw Inflation Indices issued 29 December 1986)

Year	FH	PAA	Structrl Compnts 15	Compnts & Accsories 16	Valves 48	Engine Accsories 29	Elec Wire/ Pwr Equip 61
77	929407	1702	28709302	51984627	4089051	27484005	5536534
78	959304	1702	47662134	69496183	6068502	33600859	7082325
79	960295	1673	46266376	65848882	5497118	42463621	7923393
80	945685	1684	43466023	61953448	6148405	33943671	7327159
81	1000591	1762	63964947	70838373	7265267	41463415	7403666
82	1014179	1798	64578328	78824524	7896246	45340176	7894604
83	1027874	1801	78011670	91278830	8973625	59875346	8219459
84	1044108	1825	92987065	94419522	10675846	63077232	8793496
85	1054457	1853	91091543	85522433	9040115	55730092	8545477
86	1042321	1900	98069946	82002976	8319797	49458822	8101808

Regression Results

Following are the results of the first method used to analyze the data--linear regression. The total weapon system regression results are evaluated first followed by an analysis of the individual FSG statistics.

Total Fighter Weapon System Analysis. The total fighter weapon system results are shown in Table 6. Column 1 designates the independent variables used for three models. Below the column headings, row 1 shows results of using FH as the only independent variable, row 2 uses PAA as the only independent variable, and row 3 shows results of the third model using FH and PAA as independent variables which includes t-test results of the intercept value.

TABLE 6

TOTAL FIGHTER WEAPON SYSTEM REGRESSION STATISTICS

	(1) Indep Var	(2) R^2	(3) F Value	(4) Prob > F	(5) T-Stat	(6) Prob > T
(1)	FH	.86	48.863	.0001	6.990	.0001
(2)	PAA	.28	3.054	.1187	1.748	.1187
(3)	FH				5.677	.0008
	& PAA	.87	23.603	.0008	-.791	.4547
	INTERCEPT				-.239	.8181

The coefficient of determination, R^2, is in column 2. Recall from Chapter 3 that an $R^2 > .80$ is considered to be good and indicates that the independent variable(s) are effective in explaining the variation in the regression model. Using FH alone (row 1) as an independent variable, the R^2 is .86. PAA alone (row 2) is ineffective as an explanatory variable with an R^2 of .28. However, the R^2 for using both FH & PAA (row 3) in the model is .87. The addition of PAA into the model results in only a .01 increase in explaining the variation from the regression line. This indicates that PAA is insignificant in explaining the remaining variation.

Reviewing the F-test, the cost model using both FH & PAA has a high F value (row 3, column 3) and is statistically significant with a .0008 level of significance (row 3, column 4). Furthermore, note that the total fighter weapon system statistics for the model using FH only (row 1) as the independent variable are better than the statistics for the two-variable model. The F-test shows a higher significance (.0001) and a higher F value (48.9). So when PAA is added as an independent variable, these two statistics drop which indicates that PAA is an insignificant variable to use in predicting cost.

T-test analysis from Table 6, column 6 shows highly significant results (.0001) for FH in the FH only model (row 1) and in the model using both FH & PAA (.0008) in row

3. However, PAA is not significant at the 10% level of significance (.1187) in the model using only PAA (row 2) or in row 3 for the model using both FH & PAA (.4547).

The t-test for the intercept (row 3, column 6) shows up as being insignificantly different from zero (.8181). Therefore it can be assumed that the intercept is zero. This makes it possible to apply the allocation percentage formula (4) from Chapter III for the FH and PAA regression coefficients. However, as is introduced in the next section, this may not be desirable because PAA is assigned a negative coefficient which indicates multicollinearity.

Fighter Model Collinearity Analysis. Table 7 contains the three regression models obtained from the analysis. Model 1 comes from using FH only as the independent variable, model 2 uses PAA only, and model 3 uses both FH and PAA as independent variables.

Two methods discussed in Chapter III for detecting multicollinearity are applied in the analysis of the models shown in Table 7. These two methods are: 1) large changes in the estimated regression coefficients when a variable is added or deleted, and 2) estimated regression coefficients with an algebraic sign that is the opposite of that expected from theoretical considerations or prior experience (Neter:390).

TABLE 7

TOTAL FIGHTER WEAPON SYSTEM REGRESSION MODELS

(1) FH only	
-992,777,174 + 1,941.7(FH) =	Fighter Depot Maint Cost
(2) PAA only	
-2,826,733,813 + 1,057,106.2(PAA) =	Fighter Depot Maint Cost
(3) FH and PAA	
-234,974,271 + 2,136.7(FH) - 285,954(PAA) =	Fighter Depot Maint Cost

The estimated regression coefficient of PAA in model 2 shows a large change when FH is added (model 3). The coefficient changes from +1,057,106 to a -285,954 (a delta of 1.3M). This is a large change and can be interpreted as an indicator of multicollinearity based on the first method. Also, the negative algebraic sign in model 3 for the PAA coefficient is not expected based on present depot maintenance cost allocation considerations. This is evidence of multicollinearity based on the second method mentioned above. An even more definitive example of the large change in estimated regression coefficients is found in the intercept value of the two variable model (model 3) to the model using PAA only (model 2). In this case, the value changes from -234,974,271 to -2,826,733,813 (a delta of over 1200%). Finally, in the model using both FH and

PAA, the t-statistic from Table 6 shows up as a negative number (-.791). This is evidence of multicollinearity.

The conclusion that can be drawn from the regression results for the total fighter weapon system is that 100% of the depot maintenance cost should be allocated to flying hours. The regression model using FH as the sole independent variable had the best F-statistic of the three models. The slight increase in R^2 for the two-variable model (model 3) is offset by the presence of multicollinearity of FH with PAA. Furthermore, the FH and PAA model assigns a negative coefficient to PAA which prevents the development of an allocation percentage to PAA.

Individual Fighter FSG Analysis. The regression statistics for all the individual fighter FSGs are included in Appendix C. Table 8 includes the selected fighter FSG statistics (R^2, F-test p-value, and t significance in columns 3, 4, and 5, respectively) that are discussed in this section. To read Table 8, column 1 defines the FSG title and number. Column 2 designates the independent variable(s) used in the model: row 1 includes statistics using FH only, row 2 uses PAA only, and row 3 includes data on the model using both FH and PAA. Column 3, 4, and 5 contain the statistics for the R^2, F-test p-value, and t-test probability.

Only one combined FH and PAA model had an R^2 above .90--FSG 67-Photographic Equipment (R^2=.93). However, the

TABLE 8

SELECTED FIGHTER INDIVIDUAL FSG REGRESSION STATISTICS

(1) FSG Title & Number		(2) Indep Var	(3) R^2	(4) Prob > F	(5) Prob > T
Photo Equip 67	(1)	FH	.93	.0001	.0001
	(2)	PAA	.44	.0503	.0503
	(3)	FH			.0007
		& PAA	.93	.0004	.6861
Comm Dtec & Rad Eqp 58	(1)	FH	.79	.0006	.0006
	(2)	PAA	.12	.3277	.3277
	(3)	FH			.0003
		& PAA	.88	.0005	.0461
Compnts & Accsories 16	(1)	FH	.81	.0004	.0004
	(2)	PAA	.20	.1972	.1972
	(3)	FH			.0009
		& PAA	.85	.0014	.2362
Elec Wire/ Pwr Equip 61	(1)	FH	.83	.0003	.0003
	(2)	PAA	.28	.1184	.1184
	(3)	FH			.0019
		& PAA	.83	.0019	.5743
Engs/Turb & Compnts 28	(1)	FH	.80	.0005	.0005
	(2)	PAA	.23	.1644	.1644
	(3)	FH			.0019
		& PAA	.82	.0024	.3944

model with PAA as the sole indepent variable (row 2) has an R^2 of .44. Thus, PAA is a relatively insignificant variable in explaining the amount of variation in the

regression model for FSG 67 even though its level of significance is fairly good (.0503 in column 5). In row 3, when PAA is added to the FH only model, the R^2 stays the same while the p-value of the F-test drops (.0001 to .0004) from the FH only model (row 1). T-test probabilities also drop indicating PAA's weakness in explaining cost.

Other FSGs with significant R^2s (i.e. >.80) when using both FH and PAA (row 3) as variables in a regression model are: FSG 58-Communication, Detection & Radio Equipment (R^2=.88), FSG 16-Components & Accessories (R^2=.85), FSG 61-Electric Wire/Power Equipment (R^2=.83), and FSG 28-Engines, Turbines & Components (R^2=.82). Within these four FSGs, however, the R^2 for the model with PAA alone (row 2) is insignificant ranging from .12 in FSG 58 to .28 in FSG 61. Meanwhile, the R^2 for the FH only models show fairly strong values ranging from .79 for FSG 58 to .83 for FSG 61. The model using FH alone (row 1) shows little or no increase (from a zero to .09 increase in R^2) in explanatory capability as PAA is added to the model. These statistics are indications that FH is a much stronger variable to use to predict cost.

FSGs with the highest significance of the F-test (Table 8, column 4) using both FH and PAA (row 3), correspond directly with the highest R^2s discussed above. These FSGs and corresponding F-test p-values are: FSG 67-Photographic Equipment (F-test p-value =.0004), FSG 58-

Communication, Detection & Radio Equipment (F-test p-value =.0005), FSG 16-Components & Accessories (F-test p-value =.0014), FSG 61-Electric Wire/Power Equipment (F-test p-value =.0019), and FSG 28-Engines, Turbines & Components (F-test p-value =.0024). In each of these FSG analyses, the significance of FH alone (row 1) is much higher than PAA alone (row 2). When PAA is added as the second independent variable, significance is decreased from the FH only model with one exception in FSG 58 where significance improves by only .0001.

Results of the t-test (column 5) in these five individual FSGs show results similar to the F-test with FSG 58 again being only slightly contradictory. PAA is less significant than FH when each is tested as individual cost drivers, and both FH and PAA individually become less significant when they are used together to predict cost.

These results of the R^2, F-test, and T-test, further indicate--at lower levels of data aggregation--the same problem of the inability of PAA to predict cost that is evident in the the total fighter weapon system statistics. FH is again the sole significant independent variable in explaining cost in these selected individual FSGs. Therefore, cost should be allocated 100% to FH.

Results vary in the remaining 19 fighter individual FSGs evaluated (see Appendix C). However, PAA's t-test is generally less significant in the two variable models and

the R^2 of the PAA only models show less significance that the R^2 for the FH only models. Thus, FH is shown to be the dominant independent variable.

<u>Total Cargo Weapon System Analysis</u>. Total cargo weapon system results are shown in Table 9. As in the fighter analysis above, column 1 designates the independent variables used for three models. Row 1 below the column headings shows results of using FH as the only independent variable, Row 2 uses PAA as the only independent variable, while row 3 contains results of the third model using FH <u>and</u> PAA as independent variables with t-test results of the y-intercept.

TABLE 9

TOTAL CARGO WEAPON SYSTEM REGRESSION STATISTICS

	(1) Indep Var	(2) R^2	(3) F Value	(4) Prob > F	(5) T-Stat	(6) Prob > T
(1)	FH	.91	83.813	.0001	9.155	.0001
(2)	PAA	.73	21.814	.0016	4.671	.0016
(3)	FH				4.082	.0047
	& PAA	.92	40.594	.0001	-.827	.4355
	INTERCEPT				-6.506	.0003

The R^2 (i.e. coefficient of determination) results in column 2 show a .91 value for using FH only (row 1) in the model and .73 for using PAA only (row 2) in the model. PAA

is a weak independent variable since an R^2 of >.80 (from discussion in Chapter 3) is required for an effective ability to predict cost. However, it is stronger than most other PAA models developed in this research. When using both FH and PAA in the model (row 3), the R^2 is significant at .92. However, adding PAA into the FH only (row 1) model results in the R^2 increasing by only .01. This is very similar to behavior of the fighter statistics in that FH is the only significant independent variable.

An analysis of the F-test results show the cost model using both FH & PAA statistically significant with a .0001 level of significance (column 4). However, comparing the FH only model (row 1) to the two-variable model using FH and PAA (row 3), the F-value (column 3) decreases from 83.81 to 40.59. This indicates the relative weakness of PAA as a variable making additional explanatory contribution to the model.

T-test analysis in Table 9 shows highly significant results (.0001) for FH in the models using only FH (row 1, column 6), and in row 3, column 6, when using both FH & PAA (.0047). However, PAA is not significant (.4355) in the model using both FH & PAA (row 3, column 6). The t-statistic in the model using FH and PAA (row 3, column 5) shows up as a negative number (-.827)--as it did in the fighter statistics--indicating its relative insignificance in predicting cost.

The t-test of the y-intercept (row 3, column 6) shows up as significant (.0003) and therefore the intercept is presumed not to be zero and must be considered in determining allocation percentages. However, multi-collinearity analysis results presented in the next section indicate problems which inhibit the percentage allocation process discussed in Chapter III.

Cargo Model Collinearity Analysis. The three derived cargo regression models are presented in Table 10. Model 1 uses the independent variable FH only, PAA is the only independent variable in model 2, and model 3 uses FH and PAA. As in the fighter model analysis, the following methods are used to evaluate collinearity in the cargo models: (1) large changes in the estimated regression coefficients when a variable is added or deleted, and (2)

TABLE 10

TOTAL CARGO WEAPON SYSTEM REGRESSION MODELS

(1) FH only

-1,523,289,849 + 1,943.8(FH) = Cargo Depot Maint Cost

(2) PAA only

-1,389,858,693 + 1,020,430.2(PAA) = Cargo Depot Maint Cost

(3) FH and PAA

-1,469,631,928 + 2,394.7(FH) - 284,518(PAA) = Cargo Depot Maint Cost

estimated regression coefficients with an algebraic sign that is the opposite of that expected from theoretical considerations or prior experience (Neter:390).

Similar to fighter results, the estimated regression coefficient of PAA in model 2 shows a large change when FH enters in model 3. The coefficient changes from +1,020,430 to a -284,518 (a delta of 1.3M). The large change is an indication of multicollinearity in cargo data based on method (1) described above. Again--as in the fighter data--the algebraic sign change of the PAA coefficient when FH is added to the model is not consistent with present depot maintenance cost allocation considerations. Thus, there is additional evidence of collinearity between FH and PAA.The conclusion drawn from the regression of cargo total weapon system data indicates 100% of depot maintenance cost should be allocated to the independent variable FH. Similar to results using fighter data, the F-statistics of the three models are best in the regression model using FH only as the independent variable. The presence of multicollinearity between FH and PAA offsets the slight increase in the R^2 from the FH only to the FH and PAA model. The negative coefficient assigned to PAA in the two variable model prevents a PAA allocation percentage for depot maintenance cost.

Individual Cargo FSG Analysis. Regression statistics for all 28 of the individual cargo FSGs are in Appendix D. Cargo FSGs selected for analysis in this section are in Table 11 and is read in the same manner as Table 8. It include the R^2, the F test p-value, and t significance in columns 3, 4, and 5, respectively.

Among the individual FSG breakouts for cargo aircraft, there are six models using FH and PAA (row 3) where the R^2 (column 3) is >.80: FSG 15-Structural Components (R^2=.96), FSG 16-Components and Accessories (R^2=.90), FSG 48-Valves (R^2=.90), FSG 29-Engine Accessories (R^2=.89), FSG 61-Electric Wire/Power Equipment (R^2=.86), and FSG 43-Pumps and Compressors (R^2=.84). In one of these cases--FSG 15-Structural Components--the R^2 for PAA alone is strong (.88). Of the remaining five two variable models (row 3) with high R^2s, the R^2s for PAA only regression models (row 2) are significantly weaker and range from .39 in FSG 61 to .64 in FSG 48. However, note that for FSG 61 the R^2 for the two variable model is significantly increased when PAA is added to the FH only model.

The F-test p-values (column 4) for the two variable models correspond directly with the R^2 results discussed above. These results are: FSG 15-Structural Components (F-test p-value =.0001), FSG 16-Components and Accessories (F-test p-value =.0003), FSG 48-Valves (F-test p-value

TABLE 11

SELECTED CARGO INDIVIDUAL FSG REGRESSION STATISTICS

(1) FSG Title & Number		(2) Indep Var	(3) R^2	(4) Prob > F	(5) Prob > T
Structrl Compnts 15	(1)	FH	.95	.0001	.0001
	(2)	PAA	.88	.0001	.0001
	(3)	FH & PAA	.96	.0001	.0081 .3346
Compnts & Accsories 16	(1)	FH	.88	.0001	.0001
	(2)	PAA	.62	.0072	.0072
	(3)	FH & PAA	.90	.0003	.0027 .1233
Valves 48	(1)	FH	.87	.0001	.0001
	(2)	PAA	.64	.0053	.0053
	(3)	FH & PAA	.90	.0003	.0040 .1914
Engine Accsories 29	(1)	FH	.82	.0003	.0003
	(2)	PAA	.54	.0148	.0148
	(3)	FH & PAA	.89	.0004	.0023 .0657
Elec Wire/Pwr Equip 61	(1)	FH	.69	.0028	.0028
	(2)	PAA	.39	.0533	.0533
	(3)	FH & PAA	.86	.0011	.0020 .0259
Pumps & Cmprssrs 43	(1)	FH	.81	.0004	.0004
	(2)	PAA	.60	.0089	.0089
	(3)	FH & PAA	.84	.0015	.0129 .2766

=.0003), FSG 29-Engine Accessories (F-test p-value =.0004), FSG 61-Electric Wire/Power Equipment (F-test p-value =.0011), and FSG 43-Pumps and Compressors (F-test p-value =.0015). The two variable models' F-test p-value (column 4) in FSG 15, FSG 16, and FSG 48 show significance (.0001, .0003, and .0003 respectively), however the best overall statistics for the single variable models still belong to FH with the higher R^2 in all cases. With one exception, the F-test significance is lower for the FH alone model (row 1) as compared to the FH <u>and</u> PAA model (row 3) even though R^2 values increased, which points to the weakness of PAA to predict cost. The exception, FSG 61, shows a slight F-test p-value increase from .0028 to .0011, and a significant increase in R^2 values from .69 to .86.

T-test results in column 5 of these six individual FSGs parallel results of the F-test showing the relative weakness of PAA in predicting cost. PAA alone is less significant than FH alone (FSG 15 excluded where they are equal), and both FH and PAA individually become less significant (FSG 61 excepted) when they are used together to predict cost.

Results are not as definitive as shown in the fighter individual FSG analysis, however, cargo data analysis of these selected individual FSGs level still show the relatively stronger variable to be FH. Therefore, it can

be assumed--because of the high significance of FH--that costs should be allocated 100% to FH and a model reflecting percentage allocation is not developed. One exception is FSG 61. The statistics for this FSG indicate that data from the two variable regression model should be used for allocation percentage computations.

Of the remaining 22 cargo individual FSGs evaluated (see Appendix D), the R^2 in the PAA only models range from .01 for FSG 10 and .70 for FSG 49. All are insignificant since an R^2 of >.80 (from Chapter III) is required for an effective ability to predict cost. The F-test p-value for PAA in the two variable model is only significant in five of these remaining 22 models. The weakness of PAA as an independent variable in most of the models makes it undesirable to attempt an allocation of costs between FH and PAA. However, for those two variable models which are significant, the techniques described in Chapter III would be followed. This is not pursued in this research since so few FSGs are affected.

<u>Summary of Regression Results</u>. Regression analysis of fighter and cargo aircraft data from the Recoverable Item Distribution Report of the WSCRS system gives consistent indications of the insignificance of PAA as an explanatory variable and multicollinearity between FH and PAA. Because of these results, depot maintenance costs cannot be effectively allocated between FH and PAA. In fact, the

results of the study indicate that in most cases the depot maintenance cost should be allocated 100% to FH. These initial results support the results of Larson's research. She summarized: "the problem of multicollinearity between [FH] and PAA exists and affects the model using both [FH] and PAA (Larson:92)." Even after using an additional method to account for the multicollinearity (i.e. ridge regression), Larson's resulting regression models could "not provide proportions of depot maintenance costs to [FH] and PAA (Larson:92)."

Next is an analysis using goal programming to determine if this form of linear programming can provide allocation percentages.

Goal Programming Results

The results of using fighter and cargo data in a goal programming formulation are shown in Table 12. Table 12 includes data from both total fighter weapon system (column 1) and total cargo weapon system (column 2) goal programming runs. As discussed in Chapter 3, the variable assigned to the intercept is B_0, B_1 is the FH coefficient, and B_2 is the PAA coefficient. Additionally, the values assigned to each deviation plus (d^+) and each deviation minus (d^-) variable is shown.

Goal Programming Analysis. An initial review of the results for the aggregated data for fighter and cargo

weapon systems shows that the goal programming solution includes a positive, non-zero value only for the FH coefficient. The fighter FH coefficient has a value of 691.392 and the cargo FH coefficient has a value of 426.229. This unexpected 100% allocation to FH prompted the use of two methods in attempts to bring PAA into the models.

TABLE 12

TOTAL WEAPON SYSTEM GOAL PROGRAMMING RESULTS

(1) Total fighter weapon system results			(2) Total cargo weapon system results		
B_0	=	0	B_0	=	0
B_1	=	691.392	B_1	=	426.229
B_2	=	0	B_2	=	0
d^{+}_{77}	=	0	d^{+}_{77}	=	0
d^{-}_{77}	=	178,650,320	d^{-}_{77}	=	117,588,756
d^{+}_{78}	=	0	d^{+}_{78}	=	0
d^{-}_{78}	=	59,618,875	d^{-}_{78}	=	66,333,840
d^{+}_{79}	=	0	d^{+}_{79}	=	0
d^{-}_{79}	=	82,007,365	d^{-}_{79}	=	66,395,059
d^{+}_{80}	=	0	d^{+}_{80}	=	0
d^{-}_{80}	=	69,418,306	d^{-}_{80}	=	75,998,358
d^{+}_{81}	=	0	d^{+}_{81}	=	[illegible]
d^{-}_{81}	=	39,279,810	d^{-}_{81}	=	[illegible]
d^{+}_{82}	=	0	d^{+}_{82}	=	[illegible]
d^{-}_{82}	=	0	d^{-}_{82}	=	[illegible]
d^{+}_{83}	=	32,677,360	d^{+}_{83}	=	[illegible]
d^{-}_{83}	=	0	d^{-}_{83}	=	[illegible]
d^{+}_{84}	=	157,039,503	d^{+}_{84}	=	[illegible]
d^{-}_{84}	=	0	d^{-}_{84}	=	[illegible]
d^{+}_{85}	=	115,799,670	d^{+}_{85}	=	[illegible]
d^{-}_{85}	=	0	d^{-}_{85}	=	[illegible]
d^{+}_{86}	=	103,347,800	d^{+}_{86}	=	[illegible]
d^{-}_{86}	=	0	d^{-}_{86}	=	[illegible]

The first method used is to scale down the independent variable FH for each year by a factor of 100. Because PAA totals for each year were smaller numbers, FH totals may have dominated the allocation in the goal programming process. FH totals in each fiscal year are scaled down (i.e. divided) by one hundred to make the totals more relatively equal. Additionally, several individual FSGs within fighter and cargo data were tested using the scaled FH independent variable in an attempt to bring PAA into the model. Selection criteria were based on the results of the coefficient of determination (R^2) and strength of the F-test p-value of the regression statistics (see Appendix C & D).

Following are these individual FSGs, and the reason they were selected: fighter FSG 67 was selected because of its high R^2 value (.91) and high F test significance (.0004); fighter FSG 66 was selected because the R^2 for the PAA alone regression model (.68) is higher [illegible] fighter FSG 78 was selected because the F test [illegible] increases from the PH only model (.0006) to the PH and PAA model [illegible]; however, the R^2 [illegible] model. [illegible] cargo FSG 49 was selected because the R^2 for the PAA alone regression model [illegible] is higher [illegible] explaining more [illegible]

Results of this scaled goal programming process are found in Appendix E in the same format as Table 12 above. In the scaled total fighter and total cargo results, goal programming simply scaled up the coefficients assigned to FH by the same factor that FH was scaled down by (i.e. 100). The fighter FH coefficient is assigned a coefficient of 69,135.097, and the cargo FH coefficient is assigned a coefficient of 42,622.033. Still no coefficient was assigned to PAA in the two aggregate models. The results of the scaled individual FSG results--fighter FSG 67, FSG 66, FSG 58, and cargo FSG 49 (see Appendix E)--are similar in that FH is the only independent variable given a coefficient and PAA does not enter the model.

The second method involves analyzing certain FSGs within the fighter and cargo categories using the R^2 statistic from regression analysis as sole criterion for choosing an FSG. Four FSGs with a higher R^2 for PAA than FH (see Appendices C & D) are singled out for goal programming analysis. These four are: fighter FSG 63 with an R^2 for PAA of .51 and an R^2 for FH of .37, fighter FSG 66 (PAA R^2=.68 and FH R^2=.62), cargo FSG 62 (PAA R^2=.64 and FH R^2=.39), and cargo FSG 70 (PAA R^2=.51 and FH R^2=.41).

Appendix F contains the results of this second method in the same format as Table 10 above. Goal programming results of the two fighter aircraft FSGs show that FH is the only variable assigned a coefficient. For FSG 63, FH

is given a value of .524452 for its coefficient and the FH coefficient is assigned a coefficient of 102.985 for FSG 66. However, the two cargo aircraft goal programming runs did apply a coefficient to PAA. FSG 62 from cargo aircraft data is assigned the coefficients .043 for FH and 30.682 for PAA, and cargo FSG 70 is assigned a coefficient to PAA of 311.509 and no coefficient is assigned to FH.

It is important to note here that this second method only analyzed data sets within the categories of fighter and cargo data. However, the total weapon system runs consistently point to FH as the consistently stronger independent variable and PAA to be insignificant in predicting cost.

Summary of Goal Programming. Using goal programming as a method to cross-check regression analysis results of fighter and cargo aircraft data from the Recoverable Item Distribution Report verifies that FH is the dominant of the two independent variables in predicting cost. Attempts to bring PAA into the model were unsuccessful at the total weapon system level for both fighter and cargo aircraft data. Additionally, only two of 52 individual FSG categories--cargo FSG 62 and cargo FSG 70--were found to allocate a coefficient to PAA. Goal programming consistently allocates costs 100% to FH (except for two individual FSGs described above). The third method, linear programming, is now evaluated.

Linear Programming Results

Table 13 shows the results of the linear programming model using fighter (column 1) and cargo (column 2) total weapon system data. As discussed in Chapter III, the coefficient assigned to B_1 is the FH coefficient, and B_2 is the PAA coefficient. The objective is to minimize cost for FY86 FH and PAA data.

TABLE 13

TOTAL WEAPON SYSTEM LINEAR PROGRAMMING RESULTS

(1) Total fighter weapon system results			(2) Total cargo weapon system results		
B_1	=	871.610	B_1	=	525.138
B_2	=	0	B_2	=	0

Results show fighter and cargo FH coefficients being assigned the values 871.610 and 525.138, respectively, and a zero assigned to both PAA coefficients. This equates to a 100% allocation to FH and demonstrates that PAA is a relatively weaker variable in allocating depot maintenance cost.

Four individual FSGs were selected to evaluate if PAA can be brought into the model. Fighter FSG 26 was selected because FH and PAA show similar capability to predict cost (both R^2s =.49) based on regression analysis. Fighter FSG

66 was chosen because its R^2 for PAA alone (.68) is higher than for FH alone (.62). Cargo FSG 62 and FSG 70 were evaluated using linear programming because the goal programming process assigned a coefficient to PAA--unlike all the others tested.

Table 14 shows the linear programming results for these four individual FSGs. Column 1 contains the two fighter FSG results and the two cargo FSG results are in column 2.

TABLE 14

INDIVIDUAL FSG LINEAR PROGRAMMING RESULTS

(1)		(2)	
Fighter FSG26		Cargo FSG62	
B_1 =	3.027875	B_1 =	.479453
B_2 =	0	B_2 =	0
Fighter FSG66		Cargo FSG70	
B_1 =	131.315	B_1 =	.991498
B_2 =	0	B_2 =	0

In no case is the PAA variable assigned a value for it's coefficient. Using linear programming, depot maintenance costs are allocated 100% to FH. These results are further evidence of PAAs weakness in predicting cost.

Summary of Linear Programming. As a simplified cross check of regression and goal programming, using fighter and cargo aircraft data from the Recoverable Item Distribution Report, linear programming provides further verification

that PAA is generally an insignificant variable to use in predicting depot maintenance cost. FH is the only variable that is assigned a coefficient in both the aggregate (i.e. total fighter and cargo weapon system data) and individual FSG level within the aggregate data. Linear programming consistently allocates costs 100% to FH.

Summary

In all three methods used--linear regression, goal programming, and linear programming--results are inconclusive for using FH and PAA to allocate depot maintenance costs. In regression, FH is consistently shown to be significant and PAA is not a statistically significant variable to use to explain the variation from the regression line. Additionally, the presence of multicollinearity between FH and PAA results in PAA being assigned a negative coefficient and developing allocation percentages is not feasible. The goal and linear programming methods consistently assigned coefficients to FH only which displayed the strong ability of FH to explain depot maintenance cost. There was little promise shown in the individual FSG analysis using goal and linear programming to allocate cost to PAA. The most likely FSGs were tested, and only two of 52 allocated any cost to the independent variable PAA.

In the majority of analysis, FH is the sole independent variable to show an effective capability to predict depot maintenance cost. This is interpreted to mean a 100% allocation to FH. PAA cannot be statistically proven or methodologically shown to be an effective variable to use to allocate depot maintenance cost.

V. Conclusions and Recommendations

Overview

This study addressed two research questions: 1) is it reasonable to assume that flying hours and primary authorized aircraft are appropriate variables to use for development of Air Force depot maintenance cost factors and, 2) can percentage allocations similar to those presented in Table 1 for WBS categories be validated for FSG categories through using a.) regression analysis on fighter and cargo aircraft data from the Recoverable Item Distribution Report, b.) using goal programming as an alternate modeling technique to cross check the regression analysis used in a.), and c.) a linear programming formulation as an additional cross check on the results from a.) and b.).

Conclusions drawn from the analysis of the data will first be presented followed by recommendations for further study in this area.

Conclusions

Linear Regression. FH and PAA together are not appropriate variables to use for the development of depot maintenance cost factors for cargo and fighter aircraft. FH by itself is a good independent variable based on its consistently high explanatory nature and high F-test significance. PAA is a weak variable and showed little

significance in regression analysis. Multicollinearity was also shown to decrease the effectiveness of a model using both independent variables. These problems with PAA proved to decrease the significance of FH whenever FH and PAA were used together in a model.

Percentage allocations for depot maintenance cost similar to those in Table 1 could not be validated using regression. PAA's insignificance, multicollinearity, and the strength of FH conclude that depot maintenance costs should be allocated 100% to FH. Two WBS categories--Engine Overhauls and Engine Accessories--are allocated in this manner, however, the other six WBS categories are allocated differently.

Goal Programming. Goal programming--as a cross check of regression--further verified the strength of FH as an effective variable to use for depot maintenance cost allocation. Fighter and cargo total weapon system results consistently allocated 100% of cost to FH. Goal programming did not bring PAA into the aggregated models. This verified the regression results that showed that PAA is a weak independent variable to use in predicting depot maintenance costs. The majority of results at the FSG level also allocated costs 100% to FH. Thus the WBS allocation percentages in Table 1 could not be validated using goal programming.

Linear Programming. The additional cross check using linear programming provided further verification that PAA is generally an insignificant variable to use in predicting depot maintenance cost. FH is the only variable that is assigned a coefficient in both the aggregate (i.e. total fighter and cargo weapon system data) and individual FSG level within the aggregate data. Linear programming consistently allocates costs 100% to FH.

Summary. Throughout all three approaches, except for a few isolated FSGs, FH is the sole significant variable and PAA is insignificant in explaining cost. Furthermore, results show allocation percentages at the aggregate and FSG level should be 100% to the variable FH. Although the use of FH and PAA is "intuitively appealing" and may seem logical, FH dominates in all three approaches used in this thesis. Based on this research it appears that it is more appropriate to base depot maintenance cost allocation entirely on the number of flying hours.

This research along with Larson's and Clayton & Stuewe's studies have shown that the allocation percentages in Table 1 that are currently used cannot be statistically verified using numerous programming methods.

Recommendations

More analysis of depot maintenance cost drivers besides FH and PAA is needed. Only FH and PAA were

considered in this study to test the practicality of the present method. There may be other drivers that are significant by themselves, when used with FH, or when two or more others are used together.

However, the regression models created for fighter and cargo aircraft using FH only (Tables 6, 7, 9, and 10) are good models. The goal programming and linear programming results also focus on FH. Perhaps consideration should be given to allocating depot maintenance costs entirely to FH.

Closing Remarks

This study was the third study to evaluate the present procedure to allocate depot maintenance cost using FH and PAA. The cost analysis field and cost collection is growing and developing. As better methods of collection and more years of data are collected, more and better analysis can be performed to effectively allocate depot maintenance costs.

APPENDIX A: Fighter Aircraft Data in Then Year and 1986 Dollars

WSCRS FIGHTER aircraft data in THEN YEAR DOLLARS by title and FSG #. 1
(N/S=not shown on Recoverable Item Distribution Report)

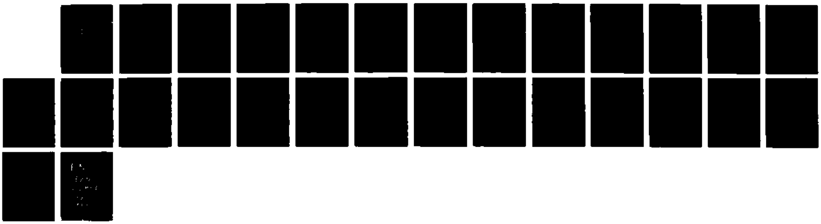
Year	FH	PAA	Weapons 10	Nuclear Ordnance 11	Fire Cont Equip 12	Guided Missiles 14	Structrl Compnts 15
77	762711	3180	287704	N/S	10651885	8516878	12125043
78	737313	3250	5690090	56	13121411	11871642	19231640
79	737376	3223	3245868	0	13603570	11053001	23336841
80	704838	3091	2479849	0	9548777	8630295	27281978
81	731847	3101	4009497	0	15980891	11012608	33669458
82	775254	3095	7482372	0	17658755	18565064	41359667
83	822056	3182	6533849	0	15207634	20435549	43550304
84	871384	3222	6497935	0	20110255	26665766	59303136
85	884004	3287	4878766	0	16847322	20658852	64412137
86	897359	3273	3237006	0	29737587	20529952	71207205

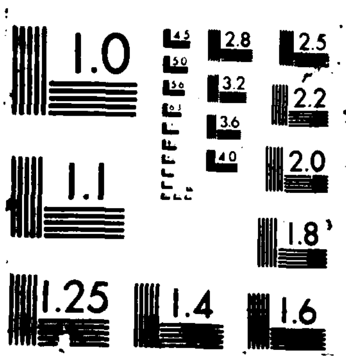
WSCRS FIGHTER aircraft data in 1986 DOLLARS by title and FSG #.
(HQ USAF/ACCE Raw Inflation Indices issued 29 December 1986)

Year	FH	PAA	Weapons 10	Nuclear Ordnance 11	Fire Cont Equip 12	Guided Missiles 14	Structrl Compnts 15
77	762711	3180	525967	N/S	19473282	15570161	22166441
78	737313	3250	9644220	95	22239680	20121427	32596000
79	737376	3223	5040168	0	21123556	17163045	36237331
80	704838	3091	3512534	0	13525180	12224214	38643028
81	731847	3101	5075313	0	20228976	13940010	42619567
82	775254	3095	8670188	0	20462057	21512241	47925454
83	822056	3182	7219723	0	16804015	22580717	48121883
84	871384	3222	6912697	0	21393888	28367836	63088443
85	884004	3287	5019307	0	17332636	21253963	66267631
86	897359	3273	3237006	0	29737587	20529952	71207205

AD-A187 625 A PRACTICALITY STUDY OF AIR FORCE DEPOT MAINTENANCE COST ALLOCATION(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYST.. B M KALISH 2/2

UNCLASSIFIED SEP 87 AFIT/GSM/LSY/87S-12 F/G 1/2 NL

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2.8
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3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

WSCRS FIGHTER aircraft data in THEN YEAR DOLLARS by title and FSG #. 2
(N/S=not shown on Recoverable Item Distribution Report)

Year	Compnts & Accsories 16	Lnch/Grnd Equip 17	Space Vehicles 18	Tires & Tubes 26	Engns/Turb & Compnts 28	Engine Accsories 29	Mech Pwr Trns Eqip 30
77	21096303	N/S	N/S	451983	42614940	21166696	77526
78	27914203	25777	N/S	1032128	52364604	32062725	115873
79	29805132	23602	N/S	491668	61857068	38929729	171450
80	30684668	N/S	N/S	248840	86486363	37352586	197307
81	40647131	62110	0	500305	76360541	56711097	463815
82	50701308	24836	0	1152871	109743303	48752914	253641
83	60773734	19191	0	1390260	142988208	72597096	438546
84	77795956	12623	0	1329485	195558332	99616726	352468
85	68068064	N/S	2828	2601708	210471391	87755782	293424
86	75145729	N/S	N/S	1430823	185927955	101178390	281114

WSCRS FIGHTER aircraft data in 1986 DOLLARS by title and FSG #.
(HQ USAF/ACCE Raw Inflation Indices issued 29 December 1986)

Year	Compnts & Accsories 16	Lnch/Grnd Equip 17	Space Vehicles 18	Tires & Tubes 26	Engns/Turb & Compnts 28	Engine Accsories 29	Mech Pwr Trns Eqip 30
77	38567282	N/S	N/S	826294	77906654	38695971	141729
78	47312208	43690	N/S	1749369	88753566	54343602	196395
79	46281261	36649	N/S	763460	96051348	60449890	266227
80	43462703	N/S	N/S	352465	122501931	52907346	279472
81	51452065	78620	0	633297	96658913	71786199	587108
82	58750067	28779	0	1335888	127164893	56492368	293906
83	67153297	21206	0	1536199	157998020	80217786	484581
84	82761655	13429	0	1414346	208040779	105975240	374966
85	70028872	N/S	2909	2676654	216534353	90283726	301877
86	75145729	N/S	N/S	1430823	185927955	101178390	281114

WSCRS FIGHTER aircraft data in THEN YEAR DOLLARS by title and FSG #. 3
(N/S=not shown on Recoverable Item Distribution Report)

Year	Bearings 31	Rope Cble Chn & Ftgs 40	A/C & Circ Equip 41	Pumps & Cmprssrs 43	Furn/Stm Dryng Eqp 44	Pipe/Hose & Fittngs 47	Valves 48
77	109247	N/S	526853	4989685	N/S	19360	1663081
78	272588	N/S	630807	6810247	N/S	190974	2690249
79	494110	N/S	466195	6687709	N/S	351761	2443015
80	431583	N/S	1212299	5635236	N/S	300472	2748642
81	406875	41478	569844	6278089	N/S	411283	4078641
82	527059	N/S	167393	10229836	N/S	375080	4951504
83	549704	N/S	121806	9826898	N/S	627801	5534308
84	1116112	N/S	158506	12472342	N/S	630390	6780298
85	907148	N/S	234948	9582679	82	517426	6114690
86	1261829	N/S	267822	10529499	N/S	770724	5823483

WSCRS FIGHTER aircraft data in 1986 DOLLARS by title and FSG #.
(HQ USAF/ACCE Raw Inflation Indices issued 29 December 1986)

Year	Bearings 31	Rope Cble Chn & Ftgs 40	A/C & Circ Equip 41	Pumps & Cmprssrs 43	Furn/Stm Dryng Eqp 44	Pipe/Hose & Fittngs 47	Valves 48
77	199720	N/S	963168	9121910	N/S	35393	3040367
78	462014	N/S	1069164	11542792	N/S	323685	4559744
79	767252	N/S	723905	10384641	N/S	546213	3793502
80	611307	N/S	1717137	7981921	N/S	425598	3893261
81	515032	52504	721322	7946948	N/S	520611	5162837
82	610729	N/S	193966	11853808	N/S	434623	5737548
83	607408	N/S	134592	10858451	N/S	693703	6115257
84	1187353	N/S	168623	13268449	N/S	670628	7213083
85	933280	N/S	241716	9858723	84	532331	6290833
86	1281829	N/S	267822	10529499	N/S	770724	5823483

WSCRS FIGHTER aircraft data in THEN YEAR DOLLARS by title and FSG #. 4
(N/S=not shown on Recoverable Item Distribution Report)

Year	Maint/Rpar Shop Equip 49	Hardwre & Abrasives 53	Comm Dtec & Rad Eqp 58	Elec Eqp Compnt 59	Elec Wire/ Pwr Equip 61	Lghtng & Lamps 62	Alrm & Sec Detec Sys 63
77	100401	2727	23744503	781829	2378023	32079	156565
78	168877	159514	26381903	1234724	3038235	13390	356575
79	127326	117867	30325152	1098727	3141529	7573	199555
80	103099	133532	30285923	995963	3578660	8770	260976
81	114306	789355	56001229	3485850	4120565	6006	215700
82	147521	212966	67427374	5084268	4982572	49121	254135
83	294377	258290	67696572	5664787	5548663	26537	463244
84	172953	374775	91669054	8617440	7826732	77575	549177
85	177552	258218	91492153	5577009	7558261	152156	633983
86	88997	359135	97432178	4630764	7466379	235885	463293

WSCRS FIGHTER aircraft data in 1986 DOLLARS by title and FSG #.
(HQ USAF/ACCE Raw Inflation Indices issued 29 December 1986)

Year	Maint/Rpar Shop Equip 49	Hardwre & Abrasives 53	Comm Dtec & Rad Eqp 58	Elec Eqp Compnt 59	Elec Wire/ Pwr Equip 61	Lghtng & Lamps 62	Alrm & Sec Detec Sys 63
77	183548	4985	43408598	1429303	4347391	58645	286225
78	286232	270363	44715090	2092753	5149551	22695	604364
79	197711	183023	47088745	1706098	4878151	11759	309868
80	146033	189139	42897908	1410712	5068924	12422	369654
81	144691	999184	70887632	4412468	5215905	7603	273038
82	170940	246774	78131372	5891388	5773548	56919	294479
83	325278	285403	74802842	6259433	6131119	29323	511872
84	183993	398697	97520270	9167489	8326311	82527	584231
85	182667	265656	94127729	5737664	7775989	156539	652246
86	88997	359135	97432178	4630764	7466379	235885	463293

WSCRS FIGHTER aircraft data in THEN YEAR DOLLARS by title and FSG #. 5
(N/S=not shown on Recoverable Item Distribution Report)

Year	Instmts & Lab Equip 66	Photo Equip 67	Gen Purp ADP Equip 70	Brshs/Pnts Slrs/Adhsv 80	Cntnrs & Pkg Sprt 81	Nonmtlic Fab Matls 93	TOTAL WEAPON SYSTEM
77	39235719	0	0	N/S	N/S	N/S	190729030
78	57123924	3026294	62072	N/S	N/S	N/S	265590522
79	44650709	2711003	168511	N/S	N/S	N/S	275508671
80	43320369	2852425	259524	N/S	N/S	N/S	295038136
81	48885270	3164694	633829	101	68347	14627	368703542
82	66888587	4541440	733952	N/S	304263	N/S	462571802
83	76616810	5571894	788542	N/S	416862	N/S	543941466
84	87936661	6836888	1034264	N/S	441127	N/S	713936976
85	99132999	6575598	1074069	N/S	657907	N/S	706637152
86	96750779	8158480	545912	N/S	293785	N/S	723774705

WSCRS FIGHTER aircraft data in 1986 DOLLARS by title and FSG #.
(HQ USAF/ACCE Raw Inflation Indices issued 29 December 1986)

Year	Instmts & Lab Equip 66	Photo Equip 67	Gen Purp ADP Equip 70	Brshs/Pnts Slrs/Adhsv 80	Cntnrs & Pkg Sprt 81	Nonmtlic Fab Matls 93	TOTAL WEAPON SYSTEM
77	71728920	0	0	N/S	N/S	N/S	348681956
78	96820210	5129312	105207	N/S	N/S	N/S	450153427
79	69333399	4209632	261663	N/S	N/S	N/S	427808495
80	61360296	4040262	367598	N/S	N/S	N/S	417901042
81	61880089	4005942	802315	128	86515	18515	466713344
82	77507053	5262387	850466	N/S	352564	N/S	536004406
83	84659459	6156789	871317	N/S	460621	N/S	601040294
84	93549639	7273285	1100281	N/S	469284	N/S	759507421
85	101988682	6765019	1105009	N/S	676859	N/S	726992955
86	96750779	8158480	545912	N/S	293785	N/S	723774705

APPENDIX B: Cargo Aircraft Data in Then Year and 1986 Dollars

WSCRS CARGO aircraft data in THEN YEAR DOLLARS by title and FSG #. 1
(N/S=not shown on Recoverable Item Distribution Report)

Year	FH	PAA	Weapons 10	Fire Cont Equip 12	Guided Missiles 14	Structrl Compnts 15	Compnts & Accsories 16
77	929407	1702	2977	1548631	57328	15703988	28435591
78	959304	1702	79076	677969	8751	28120659	41002748
79	960295	1673	79171	638755	11910	29795546	42406680
80	945685	1684	91981	1017110	13318	30687012	43739134
81	1000591	1762	113904	1010524	105381	50532308	55962315
82	1014179	1798	129836	2176440	333223	55731097	68025564
83	1027874	1801	39396	1311397	132626	70600561	82607341
84	1044108	1825	132944	1966535	33768	87407841	88754351
85	1054457	1853	118475	1285396	48647	88540980	83127805
86	1042321	1900	49881	1998726	82351	98069946	82002976

WSCRS CARGO aircraft data in 1986 DOLLARS by title and FSG #.
(HQ USAF/ACCE Raw Inflation Indices issued 29 December 1986)

Year	FH	PAA	Weapons 10	Fire Cont Equip 12	Guided Missiles 14	Structrl Compnts 15	Compnts & Accsories 16
77	929407	1702	5442	2831135	104804	28709302	51984627
78	959304	1702	134027	1149100	14832	47662134	69496183
79	960295	1673	122936	991856	18494	46266376	65848882
80	945685	1684	130285	1440666	18864	43466023	61953448
81	1000591	1762	144182	1279144	133394	63964947	70838373
82	1014179	1798	150447	2521947	386122	64578328	78824524
83	1027874	1801	43531	1449057	146548	78011670	91278830
84	1044108	1825	141430	2092059	35923	92987065	94419522
85	1054457	1853	121888	1322424	50048	91091543	85522433
86	1042321	1900	49881	1998726	82351	98069946	82002976

WSCRS CARGO aircraft data in THEN YEAR DOLLARS by title and FSG #. 2
(N/S=not shown on Recoverable Item Distribution Report)

Year	Lnch/Grnd Equip 17	Tires & Tubes 26	Engns/Turb & Compnts 28	Engine Accsories 29	Mech Pwr Trns Eqip 30	Bearings 31	A/C & Circ Equip 41
77	211765	635082	33808773	15033751	29221	183248	45877
78	N/S	744003	34560608	19824507	74783	161039	96638
79	N/S	668260	41972937	27346572	104825	287057	74524
80	N/S	521583	56833321	23964232	103596	353302	115996
81	N/S	1098794	71871148	32756098	91947	350698	168509
82	N/S	1851298	93085365	39128572	108308	368985	156285
83	N/S	1998163	136737988	54187188	174199	306030	183465
84	N/S	1224490	130077276	59292598	184372	271702	387005
85	N/S	2552275	114788575	54169649	183501	200464	115216
86	N/S	1312140	120655760	49458822	151168	253548	99100

WSCRS CARGO aircraft data in 1986 DOLLARS by title and FSG #.
(HQ USAF/ACCE Raw Inflation Indices issued 29 December 1986)

Year	Lnch/Grnd Equip 17	Tires & Tubes 26	Engns/Turb & Compnts 28	Engine Accsories 29	Mech Pwr Trns Eqip 30	Bearings 31	A/C & Circ Equip 41
77	387139	1161027	61807629	27484005	53420	335005	83870
78	N/S	1261022	58577302	33600859	126751	272947	163793
79	N/S	1037671	65175368	42463621	162772	445741	115720
80	N/S	738786	80500455	33943671	146737	500428	164300
81	N/S	1390878	90976137	41463415	116389	443922	213303
82	N/S	2145189	107862532	45340176	125502	427561	181095
83	N/S	2207915	151091699	59875346	192485	338155	202724
84	N/S	1302649	138380081	63077232	196140	289045	411707
85	N/S	2625797	118095242	55730092	188787	206239	118535
86	N/S	1312140	120655760	49458822	151168	253548	99100

WSCRS CARGO aircraft data in THEN YEAR DOLLARS by title and FSG #. 3
(N/S=not shown on Recoverable Item Distribution Report)

Year	Fire Fght Equip 42	Pumps & Cmprssrs 43	Plub/Htng/ Sanit Eqp 45	Pipe/Hose & Fittngs 47	Valves 48	Maint/Rpar Shop Equip 49	Hand Tools 51
77	7988	2841846	5926	2838	2236711	1359196	N/S
78	102554	3963031	12965	74445	3580416	1476094	343015
79	38448	4339806	12294	120318	3540144	1616077	N/S
80	38722	4535153	29007	86114	4340774	1931290	N/S
81	47559	4952787	56952	125416	5739561	1873002	N/S
82	25412	6744269	46502	139507	6814460	2940793	N/S
83	56799	8294018	24954	162021	8121131	2946708	N/S
84	76944	9340383	69245	103802	10035295	3475093	N/S
85	194759	9019771	38016	196075	8786992	3148171	N/S
86	174685	8385281	85111	235771	8319797	3593413	N/S

WSCRS CARGO aircraft data in 1986 DOLLARS by title and FSG #.
(HQ USAF/ACCE Raw Inflation Indices issued 29 December 1986)

Year	Fire Fght Equip 42	Pumps & Cmprssrs 43	Plub/Htng/ Sanit Eqp 45	Pipe/Hose & Fittngs 47	Valves 48	Maint/Rpar Shop Equip 49	Hand Tools 51
77	14603	5195331	10834	5188	4089051	2484819	N/S
78	173820	6717002	21975	126178	6068502	2501854	581381
79	59702	6738829	19090	186829	5497118	2509436	N/S
80	54847	6423729	41086	121975	6148405	2735538	N/S
81	60201	6269351	72091	158754	7265267	2370889	N/S
82	29446	7814912	53884	161654	7896246	3407640	N/S
83	62761	9164661	27573	179029	8973625	3256031	N/S
84	81855	9936578	73665	110428	10675846	3696907	N/S
85	200369	9279600	39111	201723	9040115	3238859	N/S
86	174685	8385281	85111	235771	8319797	3593413	N/S

WSCRS CARGO aircraft data in THEN YEAR DOLLARS by title and FSG #. 4
(N/S=not shown on Recoverable Item Distribution Report)

Year	Hardwre & Abrasives 53	Comm Dtec & Rad Eqp 58	Elec Eqp Compnt 59	Elec Wire/ Pwr Equip 61	Lghtng & Lamps 62	Alrm & Sec Detec Sys 63	Instmts & Lab Equip 66
77	6071	23161480	567958	3028484	50438	308792	23093767
78	411537	24110017	589152	4178572	78483	405589	36869146
79	482685	22177672	918639	5102665	19481	463338	36952670
80	436186	20030151	1101559	5172974	50298	355483	34765510
81	167877	34792766	925915	5848896	53509	460187	39268653
82	342308	41414602	1244684	6813043	57698	625038	44010314
83	491499	39938010	1684705	7438610	90031	642199	52913298
84	588914	46906363	1940219	8265886	175091	955422	62727827
85	430877	38073438	1986771	8306204	344181	786921	59618051
86	225542	43327890	1279141	8101808	499744	873389	56599005

WSCRS CARGO aircraft data in 1986 DOLLARS by title and FSG #.
(HQ USAF/ACCE Raw Inflation Indices issued 29 December 1986)

Year	Hardwre & Abrasives 53	Comm Dtec & Rad Eqp 58	Elec Eqp Compnt 59	Elec Wire/ Pwr Equip 61	Lghtng & Lamps 62	Alrm & Sec Detec Sys 63	Instmts & Lab Equip 66
77	11099	42342742	1038314	5536534	92208	564519	42218952
78	697520	40864436	998563	7082325	133022	687439	62490078
79	749511	34437379	1426458	7923393	30250	719469	57379922
80	617827	28371319	1560282	7327159	71244	503517	49242932
81	212503	44041476	1172044	7403666	67733	582515	49707156
82	396649	47989110	1442276	7894604	66857	724262	50996888
83	543093	44130398	1861552	8219459	99482	709612	58467733
84	626504	49900386	2064063	8793496	186267	1016406	66731731
85	443289	39170204	2044003	8545477	354096	809590	61335443
86	225542	43327890	1279141	8101808	499744	873389	56599005

WSCRS CARGO aircraft data in THEN YEAR DOLLARS by title and FSG #. 5
(N/S=not shown on Recoverable Item Distribution Report)

Year	Photo Equip 67	Gen Purp ADP Equip 70	Food Prep & Serv Eqp 73	Cntnrs & Pkg Sprt 81	TOTAL WEAPON SYSTEM
77	0	0	0	0	152367727
78	8591	256919	292893	N/S	202104200
79	8166	313266	1342563	N/S	220834469
80	10364	370354	222060	2220	230918804
81	29139	336161	50264	273798	309064068
82	47960	267437	32841	389462	373051303
83	29920	537313	42001	325005	472016576
84	24675	645927	116932	221778	515402678
85	20415	1016218	70019	447581	477615443
86	14390	1001944	93481	256709	487201519

WSCRS CARGO aircraft data in 1986 DOLLARS by title and FSG #.
(HQ USAF/ACCE Raw Inflation Indices issued 29 December 1986)

Year	Photo Equip 67	Gen Purp ADP Equip 70	Food Prep & Serv Eqp 73	Cntnrs & Pkg Sprt 81	TOTAL WEAPON SYSTEM
77	0	0	0	0	278551603
78	14561	435456	496429	N/S	342549492
79	12680	486438	2084725	N/S	342910666
80	14680	524581	314533	3144	327080459
81	36885	425520	63625	346580	391220339
82	55574	309892	38054	451289	432272657
83	33061	593716	46410	359122	521565277
84	26250	687156	124396	235934	548300721
85	21003	1045492	72036	460474	491373913
86	14390	1001944	93481	256709	487201519

APPENDIX C: Fighter Individual FSG Regression Statistics

To read the data in this appendix, column 1 defines the FSG title and number. Column 2 designates the independent variable(s) used in each model. The first row to the right of the title and number of each FSG includes statistics for the model using flying hours (FH) only, row 2 uses primary authorized aircraft (PAA) only, and the third and fourth row includes data on the model using both FH & PAA. Columns 3, 4, 5, 6, and 7 contain the designated statistics (i.e. the R-square, F-Value, F-probability (or p-value), t-statistic, and the t-probability, respectively).

(1) FSG Title & Number	(2) Indep Var	(3) R Square	(4) F Value	(5) Prob > F	(6) T-Stat	(7) Prob > T
Weapons	FH	0.00	0.002	0.9635	-0.047	0.9635
10	PAA	0.00	0.000	0.9835	0.021	0.9835
	FH				-0.076	0.9417
	& PAA	0.00	0.003	0.9969	0.065	0.9502
Fire Cont	FH	0.19	1.835	0.2126	1.355	0.2126
Equip	PAA	0.24	2.487	0.1534	1.577	0.1534
12	FH				0.460	0.6593
	& PAA	0.26	1.227	0.3493	0.831	0.4336
Guided	FH	0.54	9.347	0.0156	3.057	0.0156
Missiles	PAA	0.24	2.535	0.1500	1.592	0.1500
14	FH				2.128	0.0708
	& PAA	0.54	4.092	0.0665	0.052	0.9603
Structrl	FH	0.75	23.910	0.0012	4.890	0.0012
Compnts	PAA	0.19	1.849	0.2110	1.360	0.2110
15	FH				4.347	0.0034
	& PAA	0.78	12.442	0.0050	-0.997	0.3521
Compnts &	FH	0.81	34.396	0.0004	5.865	0.0004
Accsories	PAA	0.20	1.978	0.1972	1.407	0.1972
16	FH				5.466	0.0009
	& PAA	0.85	19.497	0.0014	-1.296	0.2362
Tires &	FH	0.49	7.584	0.0249	2.754	0.0249
Tubes	PAA	0.49	7.605	0.0248	2.758	0.0248
26	FH				1.313	0.2306
	& PAA	0.59	5.008	0.0447	1.317	0.2292

FIGHTER INDIVIDUAL FSG REGRESSION STATISTICS

(1) FSG Title & Number	(2) Indep Var	(3) R Square	(4) F Value	(5) Prob > F	(6) T-Stat	(7) Prob > T
Engs/Turb	FH	0.80	32.017	0.0005	5.658	0.0005
& Compnts	PAA	0.23	2.343	0.1644	1.531	0.1644
28	FH				4.824	0.0019
	& PAA	0.82	16.067	0.0024	-0.907	0.3944
Engine	FH	0.73	21.099	0.0018	4.593	0.0018
Accsories	PAA	0.25	2.692	0.1395	1.641	0.1395
29	FH				3.526	0.0090
	& PAA	0.73	9.488	0.0102	-0.376	0.7183
Mech Pwr	FH	0.01	0.046	0.8348	0.215	0.8348
Trns Eqip	PAA	0.11	1.012	0.3438	-1.006	0.3438
30	FH				1.206	0.2670
	& PAA	0.27	1.262	0.3404	-1.571	0.1601
Bearings	FH	0.59	11.524	0.0094	3.395	0.0094
31	PAA	0.27	2.894	0.1273	1.701	0.1273
	FH				2.357	0.0506
	& PAA	0.59	5.047	0.0439	0.068	0.9476
A/C & Circ	FH	0.60	12.158	0.0082	-3.487	0.0082
Equip	PAA	0.13	1.248	0.2964	-1.117	0.2964
41	FH				-3.119	0.0169
	& PAA	0.64	6.168	0.0285	0.821	0.4387
Pumps &	FH	0.23	2.388	0.1609	1.545	0.1609
Cmprssrs	PAA	0.16	1.518	0.253	1.232	0.253
43	FH				0.877	0.4097
	& PAA	0.24	1.121	0.3781	0.344	0.7412
Pipe/Hose	FH	0.34	4.062	0.0768	2.016	0.0768
& Fittngs	PAA	0.07	0.597	0.4619	0.773	0.4619
47	FH				1.785	0.1175
	& PAA	0.36	1.973	0.2092	-0.509	0.6262
Valves	FH	0.58	10.958	0.0107	3.31	0.0107
48	PAA	0.07	0.618	0.4545	0.786	0.4545
	FH				3.568	0.0091
	& PAA	0.67	7.125	0.0205	-1.403	0.2035
Maint/Rpar	FH	0.02	0.173	0.6886	-0.416	0.6886
Shop Equip	PAA	0.02	0.138	0.7203	0.371	0.7203
49	FH				-0.855	0.4207
	& PAA	0.11	0.432	0.6653	0.836	0.431

FIGHTER INDIVIDUAL FSG REGRESSION STATISTICS

(1) FSG Title & Number	(2) Indep Var	(3) R Square	(4) F Value	(5) Prob > F	(6) T-Stat	(7) Prob > T
Hardwre &	FH	0.00	0.006	0.9414	-0.076	0.9414
Abrasives	PAA	0.06	0.552	0.4787	-0.743	0.4787
53	FH				0.514	0.6228
	& PAA	0.10	0.383	0.6953	-0.872	0.4121
Comm Dtec	FH	0.79	29.643	0.0006	5.445	0.0006
& Rad Eqp	PAA	0.12	1.086	0.3277	1.042	0.3277
58	FH				6.801	0.0003
	& PAA	0.88	26.744	0.0005	-2.42	0.0461
Elec Eqp	FH	0.51	8.282	0.0206	2.878	0.0206
Compnt	PAA	0.02	0.163	0.6974	0.403	0.6974
59	FH				3.931	0.0057
	& PAA	0.69	7.954	0.0158	-2.063	0.078
Elec Wire/	FH	0.83	37.711	0.0003	6.141	0.0003
Pwr Equip	PAA	0.28	3.058	0.1184	1.749	0.1184
61	FH				4.834	0.0019
	& PAA	0.83	17.49	0.0019	-0.589	0.5743
Lghtng	FH	0.72	20.812	0.0018	4.562	0.0018
& Lamps	PAA	0.39	5.059	0.0546	2.249	0.0546
62	FH				2.98	0.0205
	& PAA	0.73	9.461	0.0102	0.445	0.6701
Alrm & Sec	FH	0.37	4.729	0.0614	2.175	0.0614
Detec Sys	PAA	0.51	8.308	0.0204	2.882	0.0204
63	FH				0.738	0.4846
	& PAA	0.54	4.19	0.0636	1.633	0.1465
Instmts &	FH	0.62	13.144	0.0067	3.625	0.0067
Lab Equip	PAA	0.68	17.069	0.0033	4.132	0.0033
66	FH				1.89	0.1006
	& PAA	0.79	13.066	0.0043	2.353	0.0509
Photo	FH	0.93	89.348	0.0001	9.452	0.0001
Equip	PAA	0.44	5.575	0.0503	2.361	0.0503
67	FH				6.431	0.0007
	& PAA	0.93	39.531	0.0004	0.424	0.6861
Gen Purp	FH	0.40	4.576	0.0697	2.139	0.0697
ADP Equip	PAA	0.00	0.001	0.9797	-0.026	0.9797
70	FH				3.808	0.0089
	& PAA	0.71	7.252	0.0251	-2.53	0.0447

APPENDIX D: Cargo Individual FSG Regression Statistics

To read the data in this appendix, column 1 defines the FSG title and number. Column 2 designates the independent variable(s) used in each model. The first row to the right of the title and number of each FSG includes statistics for the model using flying hours (FH) only, row 2 uses primary authorized aircraft (PAA) only, and the third and fourth row includes data on the model using both FH & PAA. Columns 3, 4, 5, 6, and 7 contain the designated statistics (i.e. the R-square, F-value, F-probability (or p-value), t-statistic, and the t-probability, respectively).

(1) FSG Title & Number	(2) Indep Var	(3) R Square	(4) F Value	(5) Prob > F	(6) T-Stat	(7) Prob > T
Weapons	FH	0.02	0.153	0.7057	0.391	0.7057
10	PAA	0.01	0.091	0.7704	-0.302	0.7704
	FH				2.216	0.0623
	& PAA	0.42	2.522	0.1497	-2.195	0.0642
Fire Cont	FH	0.00	0.000	0.989	-0.014	0.989
Equip	PAA	0.05	0.440	0.5258	0.663	0.5258
12	FH				-2.006	0.0849
	& PAA	0.40	2.314	0.1692	2.151	0.0685
Guided	FH	0.05	0.383	0.5532	0.619	0.5532
Missiles	PAA	0.06	0.531	0.487	0.729	0.487
14	FH				-0.134	0.8971
	& PAA	0.06	0.242	0.7914	0.377	0.7176
Structrl	FH	0.95	154.8	0.0001	12.442	0.0001
Compnts	PAA	0.88	56.608	0.0001	7.524	0.0001
15	FH				3.653	0.0081
	& PAA	0.96	78.648	0.0001	1.036	0.3346
Compnts &	FH	0.88	48.63	0.0001	6.974	0.0001
Accsories	PAA	0.62	12.808	0.0072	3.579	0.0072
16	FH				4.516	0.0027
	& PAA	0.90	32.132	0.0003	-1.751	0.1233
Tires &	FH	0.46	6.818	0.0311	2.611	0.0311
Tubes	PAA	0.35	4.304	0.0717	2.075	0.0717
26	FH				1.268	0.2454
	& PAA	0.47	3.119	0.1075	-0.384	0.7127

CARGO INDIVIDUAL FSG REGRESSION STATISTICS

(1) FSG Title & Number	(2) Indep Var	(3) R Square	(4) F Value	(5) Prob > F	(6) T-Stat	(7) Prob > T
Engs/Turb	FH	0.77	27.087	0.0008	5.205	0.0008
& Compnts	PAA	0.65	15.016	0.0047	3.875	0.0047
28	FH				1.923	0.0959
	& PAA	0.77	11.889	0.0056	-0.132	0.8985
Engine	FH	0.82	35.246	0.0003	5.937	0.0003
Accsories	PAA	0.54	9.567	0.0148	3.093	0.0148
29	FH				4.683	0.0023
	& PAA	0.89	28.26	0.0004	-2.18	0.0657
Mech Pwr	FH	0.48	52.764	0.0271	2.699	0.0271
Trns Eqip	PAA	0.21	18.764	0.1827	1.459	0.1827
30	FH				3.595	0.0088
	& PAA	0.72	9.114	0.0113	-2.491	0.0416
Bearings	FH	0.28	3.182	0.1123	-1.784	0.1123
31	PAA	0.39	5.023	0.0553	-2.241	0.0553
	FH				0.404	0.6983
	& PAA	0.40	2.33	0.1676	-1.159	0.2846
A/C & Circ	FH	0.15	1.393	0.2718	1.18	0.2718
Equip	PAA	0.04	0.315	0.59	0.561	0.59
41	FH				1.805	0.114
	& PAA	0.34	1.832	0.2292	-1.443	0.1922
Fire Fght	FH	0.22	2.193	0.1769	1.481	0.1769
Equip	PAA	0.24	2.533	0.1501	1.592	0.1501
42	FH				0.067	0.9488
	& PAA	0.24	1.111	0.381	0.488	0.6404
Pumps &	FH	0.81	34.379	0.0004	5.863	0.0004
Cmprssrs	PAA	0.60	11.776	0.0089	3.432	0.0089
43	FH				3.314	0.0129
	& PAA	0.84	18.728	0.0015	-1.18	0.2766
Plub/Htng/	FH	0.42	5.834	0.0422	2.415	0.0422
Sanit Eqp	PAA	0.48	7.438	0.026	2.727	0.026
45	FH				0.043	0.9666
	& PAA	0.48	3.256	0.1001	0.902	0.3971
Pipe/Hose	FH	0.42	5.76	0.0432	2.4	0.0432
& Fittngs	PAA	0.31	3.56	0.0959	1.887	0.0959
47	FH				1.251	0.2512
	& PAA	0.43	2.688	0.1361	-0.441	0.6722

CARGO INDIVIDUAL FSG REGRESSION STATISTICS

(1) FSG Title & Number	(2) Indep Var	(3) R Square	(4) F Value	(5) Prob > F	(6) T-Stat	(7) Prob > T
Valves	FH	0.87	52.578	0.0001	7.251	0.0001
48	PAA	0.64	14.363	0.0053	3.79	0.0053
	FH				4.198	0.004
	& PAA	0.90	30.921	0.0003	-1.446	0.1914
Maint/Rpar	FH	0.67	16.06	0.0039	4.007	0.0039
Shop Equip	PAA	0.70	18.462	0.0026	4.297	0.0026
49	FH				0.542	0.6044
	& PAA	0.71	8.563	0.0132	1.011	0.3456
Hardwre &	FH	0.00	0.000	0.9906	-0.012	0.9906
Abrasives	PAA	0.08	0.679	0.4339	-0.824	0.4339
53	FH				2.751	0.0285
	& PAA	0.56	4.403	0.0578	-2.967	0.0209
Comm Dtec	FH	0.31	3.609	0.094	1.9	0.094
& Rad Eqp	PAA	0.33	3.973	0.0814	1.993	0.0814
58	FH				0.195	0.8507
	& PAA	0.34	1.767	0.2392	0.509	0.6264
Elec Eqp	FH	0.44	6.265	0.0368	2.503	0.0368
Compnt	PAA	0.21	2.187	0.1775	1.479	0.1775
59	FH				2.663	0.0323
	& PAA	0.61	5.471	0.0371	-1.75	0.1236
Elec Wire/	FH	0.69	18.12	0.0028	4.257	0.0028
Pwr Equip	PAA	0.39	5.13	0.0533	2.265	0.0533
61	FH				4.765	0.002
	& PAA	0.86	20.877	0.0011	-2.816	0.0259
Lghtng	FH	0.39	5.187	0.0523	2.277	0.0523
& Lamps	PAA	0.64	14.231	0.0054	3.772	0.0054
62	FH				-1.633	0.1464
	& PAA	0.74	9.933	0.009	3.049	0.0816
Alrm & Sec	FH	0.59	11.364	0.0098	3.371	0.0098
Detec Sys	PAA	0.50	8.071	0.0218	2.841	0.0218
63	FH				1.198	0.2698
	& PAA	0.59	4.973	0.0453	-0.036	0.9721
Instmts &	FH	0.35	4.268	0.0727	2.066	0.0727
Lab Equip	PAA	0.15	1.465	0.2606	1.211	0.2606
66	FH				2.326	0.0529
	& PAA	0.52	3.842	0.0748	-1.605	0.1525

CARGO INDIVIDUAL FSG REGRESSION STATISTICS

(1) FSG Title & Number	(2) Indep Var	(3) R Square	(4) F Value	(5) Prob > F	(6) T-Stat	(7) Prob > T
Photo	FH	0.10	0.794	0.4024	0.891	0.4024
Equip	PAA	0.06	0.415	0.54	0.644	0.54
67	FH				0.795	0.4568
	& PAA	0.15	0.513	0.6229	-0.556	0.5981
Gen Purp	FH	0.43	5.26	0.0555	2.293	0.0555
ADP Equip	PAA	0.51	7.188	0.0315	2.681	0.0315
70	FH				-0.225	0.8295
	& PAA	0.51	3.132	0.1171	1.001	0.3555
Food Prep	FH	0.32	3.263	0.1138	-1.806	0.1138
& Serv Eqp	PAA	0.39	4.558	0.0702	-2.135	0.0702
73	FH				0.321	0.7593
	& PAA	0.40	2.038	0.2111	-0.934	0.3863
Cntnrs &	FH	0.46	4.298	0.0929	2.073	0.0929
Pkg Sprt	PAA	0.29	2.055	0.2111	1.434	0.2111
81	FH				1.348	0.2488
	& PAA	0.51	2.105	0.2374	-0.644	0.5546

APPENDIX E: Scaled Goal Programming Results

Total fighter weapon system results		Total cargo weapon system results	
B_0 =	0	B_0 =	0
B_1 =	69,135.097	B_1 =	42,622.033
B_2 =	0	B_2 =	0
d^+_{77} =	0	d^+_{77} =	0
d^-_{77} =	178,611,428	d^-_{77} =	117,577,570
d^+_{78} =	0	d^+_{78} =	0
d^-_{78} =	59,579,642	d^-_{78} =	66,323,669
d^+_{79} =	0	d^+_{79} =	0
d^-_{79} =	81,993,709	d^-_{79} =	66,388,715
d^+_{80} =	0	d^+_{80} =	0
d^-_{80} =	69,363,121	d^-_{80} =	75,996,106
d^+_{81} =	0	d^+_{81} =	0
d^-_{81} =	39,217,295	d^-_{81} =	35,255,722
d^+_{82} =	0	d^+_{82} =	0
d^-_{82} =	0	d^-_{82} =	0
d^+_{83} =	32,680,663	d^+_{83} =	83,453,402
d^-_{83} =	0	d^-_{83} =	0
d^+_{84} =	157,064,187	d^+_{84} =	103,284,076
d^-_{84} =	0	d^-_{84} =	0
d^+_{85} =	115,838,699	d^+_{85} =	41,924,577
d^-_{85} =	0	d^-_{85} =	0
d^+_{86} =	103,356,346	d^+_{86} =	42,952,071
d^-_{86} =	0	d^-_{86} =	0

SCALED GOAL PROGRAMMING RESULTS

Fighter FSG 67 results			Fighter FSG 66 results		
B_0	=	0	B_0	=	0
B_1	=	695.689	B_1	=	10,297.951
B_2	=	0	B_2	=	0
			d^+_{77}	=	0
			d^-_{77}	=	6,813,556
d^+_{78}	=	0	d^+_{78}	=	20,893,414
d^-_{78}	=	0	d^-_{78}	=	0
d^+_{79}	=	0	d^+_{79}	=	0
d^-_{79}	=	920,375.7	d^-_{79}	=	6,603,695
d^+_{80}	=	0	d^+_{80}	=	0
d^-_{80}	=	862,951.2	d^-_{80}	=	11,219,666
d^+_{81}	=	0	d^+_{81}	=	0
d^-_{81}	=	1,085,107	d^-_{81}	=	13,480,320
d^+_{82}	=	0	d^+_{82}	=	0
d^-_{82}	=	131,286.7	d^-_{82}	=	2,332,965
d^+_{83}	=	437,533.1	d^+_{83}	=	0
d^-_{83}	=	0	d^-_{83}	=	0
d^+_{84}	=	1,211,750	d^+_{84}	=	3,813,290
d^-_{84}	=	0	d^-_{84}	=	0
d^+_{85}	=	615,131.8	d^+_{85}	=	10,954,791
d^-_{85}	=	0	d^-_{85}	=	0
d^+_{86}	=	1,915,371	d^+_{86}	=	4,336,963
d^-_{86}	=	0	d^-_{86}	=	0

SCALED GOAL PROGRAMMING RESULTS

Fighter FSG 58 results			Cargo FSG 49 results		
B_0	=	0	B_0	=	0
B_1	=	9,686.749	B_1	=	307.146
B_2	=	0	B_2	=	0
d^+_{77}	=	0	d^+_{77}	=	0
d^-_{77}	=	30,472,240	d^-_{77}	=	369,799.8
d^+_{78}	=	0	d^+_{78}	=	0
d^-_{78}	=	26,705,313	d^-_{78}	=	444,601.6
d^+_{79}	=	0	d^+_{79}	=	0
d^-_{79}	=	24,341,345	d^-_{79}	=	440,091.1
d^+_{80}	=	0	d^+_{80}	=	0
d^-_{80}	=	25,374,302	d^-_{80}	=	169,145.7
d^+_{81}	=	0	d^+_{81}	=	0
d^-_{81}	=	0	d^-_{81}	=	702,418.1
d^+_{82}	=	3,030,004	d^+_{82}	=	292,561
d^-_{82}	=	0	d^-_{82}	=	0
d^+_{83}	=	0	d^+_{83}	=	98,872.948
d^-_{83}	=	4,831,925	d^-_{83}	=	0
d^+_{84}	=	13,109,936	d^+_{84}	=	489,991.2
d^-_{84}	=	0	d^-_{84}	=	0
d^+_{85}	=	8,496,864	d^+_{85}	=	0
d^-_{85}	=	0	d^-_{85}	=	0
d^+_{86}	=	10,503,289	d^+_{86}	=	392,025.9
d^-_{86}	=	0	d^-_{86}	=	0

APPENDIX F: Individual FSG Goal Programming Results

Fighter FSG 63 results		Fighter FSG 66 results	
B_0 =	0	B_0 =	0
B_1 =	.524452	B_1 =	102.985
B_2 =	0	B_2 =	0
d^+_{77} =	0	d^+_{77} =	0
d^-_{77} =	113,780.6	d^-_{77} =	6,818,893
d^+_{78} =	217,678.4	d^+_{78} =	20,888,011
d^-_{78} =	0	d^-_{78} =	0
d^+_{79} =	0	d^+_{79} =	0
d^-_{79} =	76,850.633	d^-_{79} =	6,605,288
d^+_{80} =	0	d^+_{80} =	0
d^-_{80} =	0	d^-_{80} =	11,227,464
d^+_{81} =	0	d^+_{81} =	0
d^-_{81} =	110,780.9	d^-_{81} =	13,489,194
d^+_{82} =	0	d^+_{82} =	0
d^-_{82} =	112,104.8	d^-_{82} =	2,332,501
d^+_{83} =	80,742.735	d^+_{83} =	0
d^-_{83} =	0	d^-_{83} =	0
d^+_{84} =	127,231.5	d^+_{84} =	3,810,135
d^-_{84} =	0	d^-_{84} =	0
d^+_{85} =	188,628	d^+_{85} =	10,949,507
d^-_{85} =	0	d^-_{85} =	0
d^+_{86} =	0	d^+_{86} =	4,336,239
d^-_{86} =	7,329.106	d^-_{86} =	0

INDIVIDUAL FSG GOAL PROGRAMMING RESULTS

Cargo FSG 62 results			Cargo FSG 70 results		
B_0	=	0	B_0	=	0
B_1	=	.043024	B_1	=	0
B_2	=	30.682094	B_2	=	311.509
d^+_{77}	=	0			
d^-_{77}	=	0			
d^+_{78}	=	39,527.703	d^+_{78}	=	0
d^-_{78}	=	0	d^-_{78}	=	94,732.160
d^+_{79}	=	0	d^+_{79}	=	0
d^-_{79}	=	62,397.153	d^-_{79}	=	34,716.402
d^+_{80}	=	0	d^+_{80}	=	0
d^-_{80}	=	21,112.072	d^-_{80}	=	0
d^+_{81}	=	0	d^+_{81}	=	0
d^-_{81}	=	29,378.567	d^-_{81}	=	123,358.7
d^+_{82}	=	0	d^+_{82}	=	0
d^-_{82}	=	31,943.736	d^-_{82}	=	250,201
d^+_{83}	=	0	d^+_{83}	=	32,688.458
d^-_{83}	=	0	d^-_{83}	=	0
d^+_{84}	=	85,350.173	d^+_{84}	=	118,652.2
d^-_{84}	=	0	d^-_{84}	=	0
d^+_{85}	=	251,874.8	d^+_{85}	=	468,266
d^-_{85}	=	0	d^-_{85}	=	0
d^+_{86}	=	396,602.9	d^+_{86}	=	410,077.1
d^-_{86}	=	0	d^-_{86}	=	0

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VITA

Captain Bruce M. Kalish was born 4 August 1957 in Cleveland, Ohio. He graduated from high school in Independence, Ohio, in 1975 and entered Bowling Green State University in Bowling Green, Ohio, from which he received a Bachelor of Science in Business Management/Accounting in June 1979. Upon graduation, he received a commission in the USAF through the ROTC program. He was employed with a CPA firm in the Cleveland area until entering active duty at Laughlin AFB, Texas, in April 1980. From September to December 1980 he attended Cost & Management Analysis officer training at Sheppard AFB in Wichita Falls, Texas, and was then assigned to the Air Force Electronic Warfare Center (AFEWC) at Kelly AFB in San Antonio. In January 1983 he became Chief, Cost & Management Analysis Branch for the 313th Air Division at Kadena AB, Okinawa. He returned to the U.S. in July 1984 to serve at Headquarters Air Training Command at Randolph AFB in San Antonio. While there he served as a Cost Analysis Staff Officer and DCS/Comptroller Executive Officer. He entered the School of Systems and Logistics, Air Force Institute of Technology, in May 1986. After graduating in September 1987, he will be assigned to the Directorate of Cost, Headquarters USAF at the Pentagon.

Permanent address: 6968 Carol Drive
Independence, Ohio 44131

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BLOCK 19 ABSTRACT:

The purpose of this study was to test the practicality of the present method of allocating depot maintenance costs based on the number of flying hours (FH) and primary authorized aircraft (PAA). The study addressed two basic research questions: (1) Is it reasonable to assume that flying hours and primary authorized aircraft are appropriate variables to use for development of Air Force depot maintenance cost factors? (2) Can percentage allocations presently used for FH and PAA be validated through using a.) regression analysis on fighter and cargo aircraft data, b.) using goal programming as an alternate modeling technique to cross check the regression analysis, and c.) a linear programming formulation as an additional cross check?

The study found that throughout all three statistical approaches, FH is the sole significant variable and PAA is relatively insignificant in explaining cost. Furthermore, results show allocation percentages should be 100% to the variable FH.

Although the use of FH and PAA is "intuitively appealing" and may seem logical, FH dominates in all three approaches used in this thesis. Based on this research it appears that it is more appropriate to base depot maintenance cost allocation entirely on the amount of flying hours. The allocation percentages that are currently used cannot be statistically verified using several programming methods.

Among the recommendations is that more analysis is needed to evaluate other cost drivers that are significant by themselves, when used with FH, or when two or more others are used together. However, the regression models created in this study for fighter and cargo aircraft using FH only are good models. Perhaps consideration should be given to allocating depot maintenance costs entirely to FH.

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